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Socioeconomic factors that constrain or facilitate the adoption of technologies that promote sequestration of soil carbon in East Africa

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Acronyms and abbreviations

ANOVA	Analysis of variance
BMZ/GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit *(German Agency For International Cooperation)*
BT	biotechnology
CBA	cost-benefit analysis
CC	cover crops
CCA	climate change and adaptation
CD	crop diversification
CE	crop expansion
CF	contour farming
CIAT	International Center for Tropical Agriculture
CR	crop residue
DD	drainage ditches
DI	drip irrigation
EC	erosion control
FAO	Food and Agriculture Organization of the United Nations
FLC	forest shrub land conversion
FYM	farmyard manure
GC	grassland conversion
GT	gulley treatment
HGs	household groups
IC	intercropping
IDT	improved dairy technology
IF	inorganic fertilizer
IPM	integrated pest management
IV	improved variety
KRCD	Kings River Conservation District

LL	log likelihood
MF	mixed farming
MT	minimum tillage
NGOs	nongovernment organizations
NPG	Napier grass strips
NRM	natural resource management
NT	no-till farming
OLS	ordinary least squares
PP	push and pull
S/SB	soil/stone bunds
SA	soil amendment
SB	soil bunds
SC	strip cultivation
SIC	soil inorganic matter
SLM	sustainable land management
SNNP	Southern Nations, Nationalities, and People's Region
SOC	soil organic carbon
SPSS	Statistical Package for Social Sciences
SSA	sub-Saharan Africa
ST	stone terraces
STD	sorghum terracing of Diredwa
SWC	soil water conservation
TF	tree fallow
TP	tree planting
US	United States
WOCAT	World Overview of Conservation Approaches and Technologies

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Definition of terms and concepts

A pragmatic definition of a few technical terms and concepts as used in this report is provided below.

Carbon sequestration is defined as the actual transfer and secure storage of atmospheric CO_2 into soil pools comprising soil organic matter (SOC) and soil inorganic matter (SIC). Atmospheric CO_2 is transferred into the soil carbon stock through plants. Increasing the soil carbon stock improves biomass productivity, soil quality, and water holding, and strengthens soil nutrient cycling. However, the amount of soil carbon sequestered is dependent on soil type, climate, and the nature of vegetation. Therefore, soil, land, and agricultural management practices that reduce land degradation and soil erosion also help to increase SOC.

Agricultural management (or "best" management) practices are defined as a set of practices that reduce the potentially negative impact of agricultural operations. These practices reflect household capabilities and the conditions of the farm where they are applied, and their main goal is to minimize the loss of nutrients. Some agricultural management practices that increase SOC are no-till farming (NT), cover crops, manure and sludge application, mulching, water conservation, and agroforestry. Practices with low external inputs, such as no-till, conservation agriculture, water management techniques, and the use of organic manure are also referred to as natural resource management (NRM) technologies. NRM aims at mitigating stresses associated with land degradation and nutrient depletion. However, the rate of SOC sequestration by best management practices depends on soil texture, structure, rainfall, temperature, farming system, and farm management.

Sustainable land management (SLM) practices stand for any set of comprehensive land management practices that has potential to make a significant difference, in terms of reducing land degradation and improving land productivity, in both the near future and in the long term. SLM practices comprise both technologies and approaches. Examples of SLM practices include stone/soil buds, terraces, tree planting, compost, farmyard manure (FYM), minimum tillage, contour planting, etc. Some SLM technologies have short-term benefits (e.g., farmyard manure) while others have long-term benefits (e.g., stone buds). Some SLM practices, such as stone bunds, soil bunds, terraces, etc., are also considered as NRM practices.

Adoption is defined as the degree of use of a new technology in the long-run equilibrium when the farmer has full information about the new technology and its potential. Adoption is usually described as an ongoing process occurring in a stepwise fashion: knowledge (learning about a new technology), persuasion (when adopters are convinced to accept the new technology), decision (deciding to take up the technology), implementation (putting the technology in practice), and confirmation (adopters reaffirm or reject their decision to adopt a technology). Adopter in the context of this study refers to a farmer who consistently uses a given technology.


Photo: Georgina Smith/CIAT

Executive summary

In most countries of sub-Saharan Africa (SSA), soil and nutrient loss has been an inherent problem, especially in agricultural lands; hence, the adoption of sustainable land management (SLM) practices to improve land productivity. The adoption of management practices that reduce soil erosion and degradation, improve soil quality, and mitigate nutrient loss enhance soil carbon sequestration potential for increasing farm productivity, income, and food security among farming households. Therefore, understanding the factors that determine the adoption of such practices is essential for making targeted interventions. The main objective of this report is to identify the socioeconomic factors that constrain or enable the adoption of agricultural management practices that increase soil carbon in Kenya and Ethiopia. To achieve this objective, a literature review was first conducted. This was then followed by an analysis of secondary data on agricultural management practices that increase soil carbon in Kenya and Ethiopia.

A structured literature review on SLM and agricultural practices that enhance carbon sequestration was carried out from peer-reviewed journals, reports, and working papers. A total of 90 and 54 papers were reviewed from Ethiopia and Kenya, respectively. Data from the WOCAT (World Overview of Conservation Approaches and Technologies) and CIAT databases on best-bet practices were also analyzed, which involved the conversion of qualitative data into quantitative data. The households were then clustered into three homogeneous groups using agglomerative hierarchical analysis, based on the adoption of crop and forage, water harvesting, and carbon sequestration enhancing practices. The three categories were further categorized into two deriving the dependent variable whereby households that had adopted carbon-enhancing practices were assigned a dummy variable of 1 and the remaining two assigned a value of 0. A probit model was used to estimate the effect of household characteristics (from the dataset) on the dependent variable distinctly in the two countries.

The results from the review in both countries revealed that basic econometric models (logit, probit, and tobit) were used in analyzing the adoption of carbon-enhancing SLM practices. Descriptive and inferential methods of analysis – e.g., ordinary least squares (OLS) regressions, correlations, chi-square, t-test, and analysis of variance (ANOVA) – were also used in some analyses. Common practices such as minimum tillage, application of fertilizer and manure, agroforestry, soil/stone bunds, terracing, and intercropping were observed in both countries. The determinants of adoption were varied and exhibited four categories of factors: socioeconomic, plot-level, biophysical, and institutional.

The results of the probit regression for Kenya show that access to technical assistance, off-farm income, and benefits vs maintenance cost had a negative influence on adoption. These findings suggest that households have inadequate technical assistance, are resource-constrained, and the costs of SLM technologies are high, hence constraining adoption. Market orientation and gender were positive and significant, implying that joint household decisions and access to markets are an incentive to adoption. Comparatively, in

Ethiopia, knowledge of technology use, planting as an establishment activity, market orientation, and reduced land for cultivation had a negative significance on adoption. This indicates that households lack proper knowledge of the SLM technologies in use and have small land sizes that are sufficient only for producing commodities for subsistence use, thus burdening their adoption capacity. The maintenance costs of inputs, cheap labor, and benefits vs establishment costs had a positive significance, implying that cost-effective technologies and availability of labor are critical drivers of adoption.

The study concludes that the adoption of carbon-enhancing SLM practices is variedly influenced by socioeconomic and external factors, which are dependent on the nature of technology, locality, and prevailing conditions. The review reveals that the capacity of farmers, incentives derived from the adoption of SLM technologies, and the provision of services played an important role in the adoption of such practices in both countries. Notably, the analysis shows that net returns, knowledge/information on the technology in question, and market orientation were crucial factors influencing adoption. There is an urgent need for a policy formulation framework and development partners to facilitate the dissemination of information and to provide technical assistance and training, which would enhance the knowledge, skills, and capacity required for implementing such technologies. The development of cost-effective SLM practices in both the short and long run, and that fit market needs, is plausible for scaling up adoption. Also, access to credit facilities and encouragement of off-farm income-generating activities would be a milestone in improving the adoption of SLM carbon-enhancing technologies. The review recommends further research on a combination of socioeconomic factors that can support the adoption of specific technologies in a given context. This would provide a better understanding on the most significant constraining or enabling factors to the adoption of carbon-enhancing agricultural practices and help design policies aimed at increasing their uptake.


Photo: Georgina Smith/CIAT

1. Introduction

Understanding the factors that affect the adoption of soil carbon-enhancing agricultural practices is essential for targeting and planning interventions by government, development practitioners, and nongovernment organizations (NGOs). Agricultural management practices comprise a number of key characteristics that may affect their adoption decision at the farm level in one way or another (Adesina and Baidu-Forson, 1995). The literature on the adoption of agricultural technologies, including on sustainable land management (SLM) practices that reduce soil and nutrient loss through degradation, is extensive (Adimassu et al., 2016; Feder and Umali, 1993; Rogers, 1995; Sunding and Zilberman, 2001). In areas where soil erosion is common, nutrient depletion occurs and this causes the land to become unproductive (Bewket and Sterk, 2002; Kassie et al., 2009a). In response, farmers tend to invest in agricultural and SLM practices that have potential to improve land productivity (Liniger et al., 2011). The adoption of agricultural practices that have potential to improve soil organic carbon, in particular, has potential for enhancing farm productivity, income, and food security (Bekele and Drake, 2003).

Evidence from published research shows that the most important part of agricultural research, development, and innovation occurs only when farmers adopt and implement agricultural practices that enhance soil carbon (Koirala et al., 2015; Powlson et al., 2011). Improving soil organic carbon is important because it improves soil properties, which, in turn, ensures the sustainability of soil functions that are critical for ensuring that ecosystem functioning is maintained and hence crop and livestock production (Powlson et al., 2011). However, in East Africa, the adoption of agricultural management and SLM practices that enhance soil carbon by farmers is still limited (Adimassu et al., 2014; Bewket, 2007). An analysis of the factors that influence the adoption of carbon-enhancing practices by farmers can help to unravel what constrains or facilitates farmers' ability to invest in these practices.

Evidence from the literature shows that various factors influence the adoption of soil carbon-enhancing practices, such as households' socioeconomic characteristics, biophysical characteristics, plot and farm characteristics, and institutional factors (Gebremedhin et al., 1999; Requier-Desjardins et al., 2011; Shiferaw and Holden, 1998, 2001). Variation exists, however, in the way different studies categorize these factors. Some studies categorize these factors into (i) economic, social, and institutional (e.g., Akudugu et al., 2012); (ii) economic, social, physical, and technical factors, and risk attitude of the farmers (e.g., Kebede et al., 1990); (iii) farmers' characteristics, farm structure, institutional characteristics, and managerial structure (e.g., McNamara et al., 1991); (iv) information, economic, and ecological (e.g., Nowak, 1987); (v) human capital, production, policy, and natural resource characteristics (e.g., Wu and Babcock, 1998); and (vi) institutional, technological, economic, financial, physical, human, cultural, and household-specific factors (e.g., Obayelu et al., 2017).

This report comprises the knowledge synthesized from both the literature review and the findings derived from analyzing secondary data contained in the WOCAT database. It aims to identify the socioeconomic factors that constrain or facilitate the adoption of agricultural management practices (both physical and agronomic) that enhance the sequestration of soil carbon in Kenya and Ethiopia. Enhanced understanding of the constraining or enabling factors can be used as a guide in the development of well-tailored policies that can promote the effective adoption of practices and technologies that enhance soil organic carbon in East Africa, and potentially in other areas of sub-Saharan Africa (SSA).

The report is organized as follows: In section 2, we present the materials and methods used in reviewing the literature and in the analysis of secondary data and introduce our focus countries. The main socioeconomic factors that constrain or enable the adoption of soil organic carbon-enhancing practices – based on the reviewed literature – are discussed and summarized in section 3. Section 4 contains the results and discussion of the socioeconomic factors (contained in the WOCAT and CIAT best-bet practices databases) that constrain or facilitate the adoption of practices and technologies that promote carbon sequestration in Kenya and Ethiopia (www.wocat.net). The conclusions and recommendations are provided in section 5.

Photo: Georgina Smith/CIAT

2. Materials and methods

2.1 Literature review

The information contained in the review section of this report was derived from published peer-reviewed journal papers, reports, and working papers – mainly the digital literature. However, a few hard copies were also considered. Following a framework described by Kruse (2007), the review starts by providing a list of the key terms that were used in the literature search. Some of the keywords that were used in the electronic search are adoption, SLM practices, willingness to pay, socioeconomic factors, constrain, affect, facilitate, determinants, investment, willingness to accept, land management, agricultural practices, sequestration, soil carbon, the economics of SLM, Ethiopia, and Kenya. The review was systematically structured and made explicit through a design that is reproducible for identifying, evaluating, and interpreting the existing body of knowledge. This was then followed by a detailed examination of the socioeconomic factors that can constrain or facilitate the adoption of practices and technologies that increase soil carbon. For the detailed examination, a database containing various socioeconomic literature was created in Microsoft Excel and then summarized in Microsoft Word. This was followed by recording the direction (e.g., positive or negative) and the frequencies with which each of the socioeconomic variables constrains or facilitates the adoption of different practices or technologies[1] that enhance soil carbon sequestration.

The most important technologies considered are stone bunds (level/graded), soil bunds (level/graded), Fanya juu (level/graded), tree planting, compost, farmyard manure (FYM), minimum tillage, contour ploughing, gully treatment, mixed farming, drainage ditch, intercropping, stone terraces, conservation agriculture, wood shrub contour, tree fallow, inorganic fertilizer, and the use of crop residue. Physical practices such as stone and soil bunds were considered as practices whose soil carbon sequestration benefits take a long time to be realized (Liniger et al., 2011). Agronomic practices are considered practices whose carbon sequestration benefits take a short time to be realized. This is because agronomic practices do not remove considerable areas from cultivation when compared with physical practices.

2.2 Analyzing the secondary data

We collated household-level data on various socioeconomic variables such as human, natural, financial, and physical capital, and access to markets and information (Table A1). Since we are interested in identifying the socioeconomic factors that facilitate or constrain the adoption of SLM technologies (Table A2) and that enhance carbon sequestration and the available data are largely qualitative and secondary in nature, we had to first transcribe all the socioeconomic variables collected from households that had implemented different SLM technologies – contained in the WOCAT (www.wocat.net) and CIAT-led best-bet (Sommer et al., 2016) databases – into quantitative variables. The transcribed data comprised categorical, ordinal, and continuous variables.

1 The terms *practices* and *technologies* have been used synonymously throughout this report.

The quantitative data were then used to cluster the households into three homogeneous groups (HGs) based on the households' main objectives and purpose of implementing the SLM practices. The Statistical Package for Social Sciences (SPSS) was used to cluster the households. We used an agglomerative hierarchical analysis of SPSS that reduces the dimensionality of the main variables by clustering households into more or less homogeneous groups. The main variables considered in clustering the households were (a) farmers' perceptions of SLM practices in terms of their impact on sequestering carbon (such as a reduction in soil erosion and land degradation, restoration of degraded lands, increase in biomass, improved biodiversity, and improved groundwater filtration), (b) the type of land where SLM practices are used (i.e., forest/woodland, cropland, and grazing land/grassland), (c) the category of SLM technology as perceived by the researchers who collected and recorded the data (such as vegetative, agronomic, structural, management, and several different interactions of these SLM technologies), (d) the unique group to which the different technologies belong as perceived by the researchers (i.e., windbreak, minimal soil disturbance, area closure, water diversion, and multiple cropping), and (e) the strength of the different practices in sequestering carbon based on researchers' perceptions of their effectiveness in protecting against soil erosion and in adding organic matter using a five-point Likert scale (this scale can balance both sides of a neutral option, creating low bias measurement even if the actual scale varies).

The clustering seeks to maximize between-cluster variance and to minimize within-cluster variance (Figures 1 and 2). We use three groups at a rescaled distance of 1 in both Kenya and Ethiopia for our analysis. We refer to the three group types as (i) the crop and forage farmers' group, (ii) the water harvesting and/or drainage farmers' group, and (iii) the carbon sequestration farmers' group. We developed these categories by "letting the data speak" and not explicitly based on theory. The crop and forage group (HG1) comprises households that implement SLM practices with the aim of increasing the crop (e.g., through better crop and residue management) and livestock yield (e.g., through increased forage). The water group (HG2) implements SLM technologies mainly for the purpose of improving their ability to harvest water and/or to improve water drainage. The carbon sequestration group (HG3) implements SLM technologies with the reduction in soil erosion and land degradation as its main goal. We use the classification into the three groups or types in our subsequent analysis (Table A3). A summary of the main aggregating variables for the three groups of households is presented in Table A4.

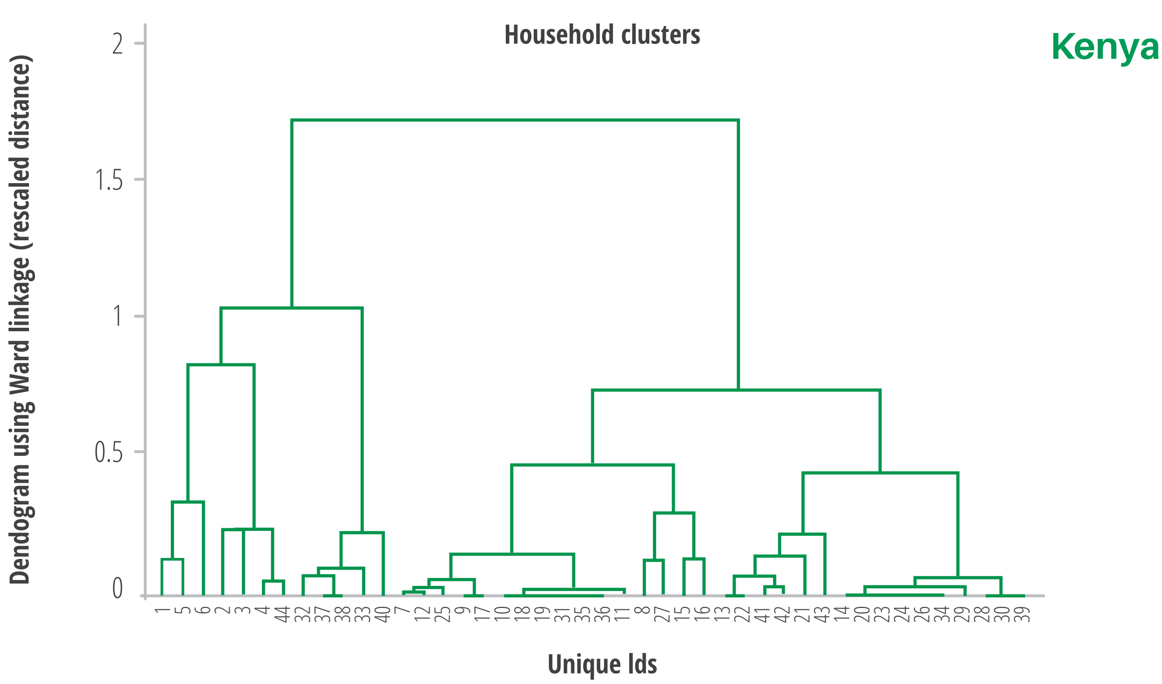

Figure 1 The agglomerative hierarchical clustering of households in Kenya into relatively homogeneous household groups (HGs). At a rescaled distance of 1.5, 1.0, and 0.5, we had two, three, and five HGs, respectively. Source: WOCAT database.

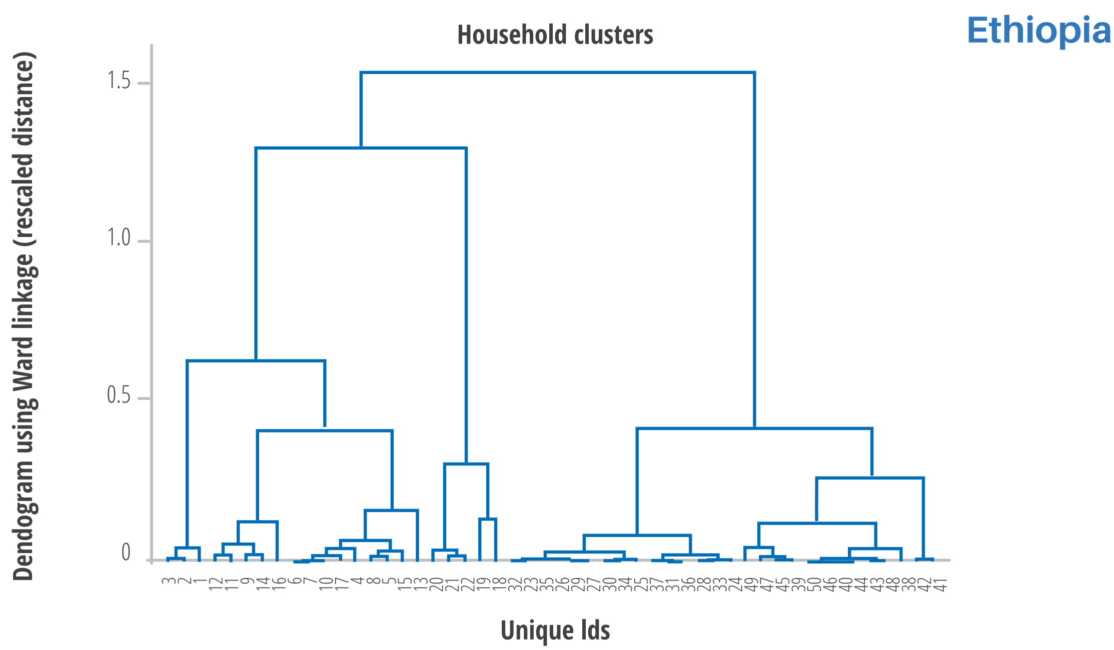

Figure 2 The agglomerative hierarchical clustering of households in Ethiopia into relatively homogeneous household groups (HGs). At a rescaled distance of 1.5, 1.0, and 0.5, we had two, three, and five HGs, respectively. Source: WOCAT database.

2.2.1 Statistical analysis

i) Testing the differences between the three household groups

Using Stata 14, a Shapiro-Wilk test was run on all the variables to test whether the socioeconomic data were normally distributed (Sheskin, 2004). Most of the socioeconomic variables in both Kenya and Ethiopia followed a non-normal distribution, except the gender of the households, access to off-farm income, and benefits versus the estimated costs in both the short and long run, that is, most of the aggregating variables had a strong left-sided frequency distribution (Tables 1 and 2). In addition, the dataset contained both discrete and continuous variables. Thus, to test whether the null hypothesis (H_o) that all the socioeconomic variables are independent among the three HGs in both countries (Table A3), we opted to use both parametric and non-parametric tests. A non-parametric Pearson chi-square and analysis of variance (ANOVA) were used for categorical variables and continuous variables, respectively (Beasley and Schumacker, 1995; García-Pérez and Núñez-Antón, 2003). A comparison procedure including Bonferroni corrections of *P* was then applied only if the Kruskal-Wallis test indicated an overall existence of differences.

Table 1 A summary and distribution for some selected socioeconomic variables in **Kenya**

VARIABLE	W	V	z	Prob>z
Access to clean water	0.86	5.80	3.72	0.00010
Access to market	0.81	7.97	4.39	0.00001
Cost of labor	0.15	35.83	7.57	0.00000

VARIABLE	W	V	z	Prob>z
Maintenance cost	0.18	34.62	7.50	0.00000
Cost of inputs	0.20	33.91	7.46	0.00000
Intensity of land use (characteristics)	0.75	10.80	5.04	0.00000
Gender of the household head	0.98	0.88	-0.26	0.60384
Market orientation	0.91	3.90	2.88	0.00198
Tenure security (landowner)	0.87	5.41	3.57	0.00018
Land size (ha)	0.92	3.33	2.54	0.00549
Access to off-farm income	0.79	8.92	4.63	0.00000
Access to energy	0.78	9.53	4.77	0.00000
Increased animal production	0.70	12.71	5.38	0.00000
Increased fuelwood	0.86	5.83	3.73	0.00010
Strength of soil carbon sequestration	0.72	12.10	5.28	0.00000
Benefits vs installation cost (short run)	0.95	2.17	1.64	0.05065
Benefits vs installation cost (long run)	0.96	1.60	1.00	0.15931
Benefits vs maintenance cost (short run)	0.91	3.71	2.77	0.00277
Benefits vs maintenance cost (long run)	0.93	2.93	2.28	0.01146

Table 2 A summary and distribution for some selected socioeconomic variables in **Ethiopia**

VARIABLE	W	V	z	Prob>z
Access to clean water	0.81	8.58	4.58	0.00000
Access to market	0.84	7.06	4.16	0.00002
Cost of labor	0.44	26.10	6.95	0.00000
Maintenance cost	0.27	34.07	7.52	0.00000
Cost of inputs	0.20	33.91	7.46	0.00000
Intensity of land use (characteristics)	0.78	10.16	4.94	0.00000

VARIABLE	W	V	z	Prob>z
Gender of the household head	0.97	1.02	0.05	0.47933
Market orientation	0.41	27.30	7.05	0.00000
Land size	0.92	3.62	2.74	0.00301
Access to off-farm income	0.97	1.32	0.60	0.27342
Access to energy	0.78	10.17	4.94	0.00000
Increased fuelwood	0.88	5.61	3.67	0.00012
Strength of soil carbon sequestration	0.66	15.97	5.90	0.00000
Benefits vs Installation cost (short run)	0.96	1.72	1.16	0.12304
Benefits vs Installation cost (long run)	0.97	1.35	0.64	0.25969
Benefits vs maintenance cost (short run)	0.96	1.68	1.11	0.13304
Benefits vs maintenance cost (long run)	0.96	1.87	1.33	0.09037

ii) Identification

Since we are interested in identifying factors that constrain or facilitate the adoption of carbon-enhancing practices, it is important to establish exogenous variation in our household characteristics. This will then enable us to identify whether the selected socioeconomic characteristics have a positive or negative effect on the adoption of soil carbon-enhancing practices. The challenge for this approach, however, is that we need a dataset in which the dependent variable can have only one of two possible outcomes [i.e., 1 (for adopters) or 0 (for non-adopters)]. This is because we are interested in knowing how specific household characteristics affect the behavior of the household toward adopting technologies that enhance sequestration of soil carbon or not. This study uses secondary data recorded in the WOCAT database (www.wocat.net). Nevertheless, the data contained in the WOCAT database were not collected with the idea of studying socioeconomic factors that influence the behavior of the households to adopt or not adopt. Consequently, we had to develop – from the existing data – the two categories of households: the adopters and non-adopters of practices that enhance soil carbon sequestration. This was done by assigning all the households in HG3 a dummy value of 1, and those in HG2 and HG3 a dummy value of 0. By doing so, we implicitly assumed that all the households are equally likely to provide information correctly, or that any propensity to under- or over-report does not correlate with the factors constraining or facilitating the adoption of SLM practices that enhance the sequestration of soil carbon. We believe this is plausible. Therefore, using Stata release 14, we estimated a probit model – since the dependent variable is censored at zero – as shown in Equation 1.

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where Y_i represents the adoption of soil carbon-enhancing technology for household i, X_i is a vector of characteristics (including access to infrastructure and impact of technologies on household livelihoods) for i, and ε_i is the random error variable associated with the equation. If a specific household characteristic facilitates the adoption of a soil carbon-enhancing technology, then β_1 will be greater than 0 (i.e., $\beta_1>0$). if, in contrast, a specific household characteristic constrains the adoption of a specific carbon sequestration-enhancing technology, then we would expect β_1 to be less than 0 (i.e., $\beta_1<0$).

Photo: Georgina Smith/CIAT

3. A review of the literature on determinants of the adoption of SLM practices

The review was limited to East Africa, specifically Kenya and Ethiopia, in order to limit the scope and challenges associated with the literature review. A brief description of the biophysical and socioeconomic characteristics of Kenya and Ethiopia is provided in Appendix 1. The agricultural practices considered in this review are those that the reviewed studies show as having some potential to reduce the rate of soil erosion and land degradation – thereby mitigating the loss of the already sequestered carbon stocks – or those that accelerate the rate of soil carbon accumulation in the soil. The reader should, therefore, interpret the findings with this caveat in mind. The carbon sequestering and carbon stock potential of various SLM technologies as showed by some of the reviewed literature is summarized in Table A5.

3.1 Nature of the reviewed literature

In Ethiopia, about 93% of the 80 papers, reports, and working papers considered in this review use the most common econometric models in the adoption literature – such as probit, logit,[2] and tobit[3] – in their analysis, while only about 5% and 2% used techniques such as ordinary least squares (OLS) regression and the factor approach, respectively. The socioeconomic factors that had a positive (enabling) or negative (constraining) effect on the adoption of soil carbon-enhancing practices by farmers were identified using the logit, tobit, and probit models. The average sample size for households in the reviewed papers was about 350, with a standard deviation of 500. A majority of the reviewed studies (61%) had been conducted in the regions of Tigray and Amhara in the north and northwestern part of Ethiopia, respectively, while 39% had been conducted in Oromia, Southern Nations, Nationalities, and People's Region (SNNP), and the mixed region. Both Tigray and Amhara are situated in a highland (where torrential rain is not uncommon), characterized by a rugged landscape, and are therefore prone to land degradation and soil erosion (www.idp-uk.org).

In Kenya, about 30% of the 52 papers reviewed had used probit, logit, and tobit models for analyzing the socioeconomic factors affecting the adoption of SLM practices. About 52% of the studies used descriptive and inferential methods of analysis (i.e., OLS regressions, correlations, chi-square, t-test, and ANOVA). A few studies (i.e., 7%) used cost-benefit analysis (CBA), marginal rate of returns, and partial budgeting to assess the economic viability and profitability of adopting certain SLM practices. The reviewed studies in Kenya showed that SLM practices are being used – although in varying intensities – in many regions across the country:

2 The logit and probit models are similar except in the distribution of error terms. The logit model assumes a logistic distribution, while the probit model assumes a standard normal distribution. These two models do not take into account how farmers actually invest in their land, and as such the results from both models are similar. The multivariate probit model looks at how farmers make multiple adoption decisions simultaneously. The multivariate profit estimator also allows the possibility of a correlation across a group of practices in the discrete choice process.

3 The tobit model considers not only whether the farmers adopt a practice or not but also how much the farmers invest in their land or farm plots.

Nairobi, Coast, Western/Nyanza, Central, Eastern, and Rift Valley regions. A positive implication of this finding could be that the adoption of these practices has become widespread and thus a positive step toward achieving sustainable lands. While there is no standard measure against which the farmers that use certain SLM practices should be weighed, the number of households studied could be an indicator. For instance, the average sample size of the households studied in the reviewed papers in Kenya is 948, with a standard deviation of 2,357, which is higher than the number in Ethiopia. The other implication – albeit negative – for this review summary could be that land degradation is rampant in Kenya, forcing households to employ various techniques that would improve the quality of their land. Hence, an urgent need exists for development and policy interventions to change the current state.

The literature points out some dominance in land management practices adopted across regions. For example, in arid and semi-arid regions (e.g., Eastern, Coast, and Lower Central) where rainfall is low and unreliable, soils have poor water retention capacity and soil erosion is more rampant, leading to low soil organic matter and hence declining fertility. In these areas, the common practices used include building ridges, applying fertilizer, planting cover crops (including trees and grasses), and harvesting rainwater (Mganga et al., 2015; Okeyo et al., 2014). Even though the high-potential areas (such as the Central Highlands, parts of the Rift Valley, and the Western region, including Nyanza) have well-drained, fertile soils and receive reliable rainfall, the population pressure poses a challenge. This has led to intensive agricultural production and hence a decline in soil fertility. In the Central, Rift Valley, and Western regions, soil nutrient replenishment measures such as fertilizer and manure application are common (Chikowo et al., 2014; Mugwe et al., 2009).

3.2 Review findings

3.2.1 Socioeconomic factors

Age of the household head

The results from both countries indicate that, as expected, the effects of different socioeconomic factors on the adoption of different soil carbon-enhancing technologies differ. This is because the identified factors affect farmers' decisions negatively or positively. The effect of age on the adoption of SLM practices, for example, is mixed (Tables 3 and 4). The age of the household head tends to constrain the adoption of soil/stone bunds[4] in about 75% of the studies conducted in Ethiopia (Table 3), that is, progression in age of the household head has a negative effect on the adoption of technologies such as soil bunds. This could be because, as the age of the main decision maker increases, his/her planning horizon shrinks. It could also be due to the inability to have the energy required for adopting, implementing, and maintaining the soil bund practice. The opposite is true in that the adoption of soil/stone bunds seems less constraining for younger household heads who are relatively healthier and stronger (see column 1 in Table 3), suggesting that any policy (e.g., on extension) aiming to promote soil/stone bunds as a practice that mitigates the loss of soil carbon may need to consider critical demographic characteristics, such as age of the household head.

Table 3 The effect of different socioeconomic characteristics on the adoption of different agricultural practices that have potential to increase soil carbon in both the short and long term in **Ethiopia**

PRACTICE	AGE OF THE HH HEAD[a]	EDUCATION[a]	GENDER[a]	HOUSEHOLD SIZE[a]	ECONOMIC ACTIVITY[a]	OFF-FARM INCOME[a]	CREDIT[c]	ACCESS TO INFORMATION[c]	EXTENSION SERVICES[c]	SOURCE
SB	+	+	+			+		+	+	Kassie et al. (2008) Ketema and Bauer (2012)
SB	+	+	+			-		+	-	Kassie et al. (2009b, 2008)
SB	-	+			+				+	Deininger and Jin (2006)
SB	-	+	+		+	+	-	+	-	Benin and Pender (2001); Gebremedhin et al. (1999); Hagos and Holden (2006)
SB	-	+	+			+	+	+	+	Gebremedhin et al. (2003)
SB	-	+	+	-		+		+	+	Anley et al. (2007); Gebremedhin et al. (2003)

4 See Appendix Table A1 for a brief description of the practice (this applies to all subsequent practices).

PRACTICE	AGE OF THE HH HEAD[a]	EDUCATION[a]	GENDER[a]	HOUSEHOLD SIZE[a]	ECONOMIC ACTIVITY[a]	OFF-FARM INCOME[a]	CREDIT[c]	ACCESS TO INFORMATION[c]	EXTENSION SERVICES[c]	SOURCE
SB	-	+	+	-		+		+	+	Hagos and Holden (2006)
SB	+	-	-			+	-	+		Shiferaw and Holden (1998)
SB	-	-				-		+		Tadesse and Belay (2004)
SB	-	-			+	-		+	+	Gebremedhin and Swinton (2003)
S/SB	-	-	-		+				-	Gebregziabher et al. (2013); Tesfaye et al. (2014); Teshome et al. (2016)
S/SB	-	+	+	+	+	-	+	+	+	Teshome et al. (2016)
S/SB	+	+	+		+		+	+	+	Mengstie (2009)
DD	+	+	-	-		+		+		Benin and Pender (2001)
GT	-	+	+	-		-				Gebregziabher et al. (2013)
MF	+	+	+		+	-	+	+	+	Bekele and Drake (2003); Deressa et al. (2009)
MF	-	+	+	+	+	+	-	+	+	Schmidt and Tadesse (2012)
MF	-	+	+	+	+	+	+	+	+	Asrat et al. (2004); Gebremariam and Edriss (2010)
C/FYM	-	+	+	-	-	+	+		-	Pender and Gebremedhin (2006)
C/FYM	-	+	-	-			+	+	+	Kassie et al. (2009b); Pender and Gebremedhin (2006)
FYM	+	+	+			+	-			Gebremedhin et al. (2003)
FYM	-	-	-				+		+	Benin (2006)
FYM	+	-	-				+		+	Teklewold et al. (2013)
TP	-	+	+	+	+	+			+	Gebregziabher et al. (2013); Holden et al. (2004); Mengstie (2009)
TP	+	+	+	+	+		+	+		Benin and Pender (2001)
TP		-								Gebremedhin and Swinton (2003)
MT	+	-	-			-	+		-	Pender and Gebremedhin (2006)
MT	-	+	+		-			+	+	Kassie et al. (2009b)
MT	-	-	-		+		+		+	Benin (2006)
IC	+	-	-	+	+	-	+		+	Pender and Gebremedhin (2006)
CP	+	-	+			-	+		+	Pender and Gebremedhin (2006)

MT = minimum tillage, **IC** = intercropping, **CP** = contour ploughing, **TP** = tree planting, **FYM** = farmyard manure, **C** = compost, **GT** = gully treatment, **MF** = mixed farming, **DD** = drainage ditch, **S/SB** = soil/stone bund, **SB** = stone bud, **HH** = household. The letters [a, b, c] stand for socioeconomic factors and institutional and plot-level characteristics.

Table 3 The effect of different socioeconomic characteristics on the adoption of different agricultural practices that have potential to increase soil carbon in both the short and long term in **Ethiopia (cont'd)**

PRACTICE	DISTANCE TO MARKET[c]	LAND SIZE[b]	LAND TENURE[b]	FARM SIZE[b]	PLOT SIZE[b]	PLOT SLOPE[d]	HERD SIZE[a]	SOURCE
SB	+	+		+				Kassie et al. (2008); Ketema and Bauer (2012)
SB		+	-	-		+	-	Kassie et al. (2008, 2009b)
SB		-	-			+	+	Deininger and Jin (2006)
SB	+	-	-	+	+	+	+	Benin and Pender (2001); Gebremedhin et al. (1999); Hagos and Holden (2006)
SB	+	+	+				-	Gebremedhin et al. (2003)
SB	-	+	+				-	Anley et al. (2007); Gebremedhin et al. (2003)
SB	-	+	+		+	+	-	Hagos and Holden (2006)
SB		+	+	+			-	Shiferaw and Holden (1998)
SB		+	+	-			+	Tadesse and Belay (2004)
SB		+	+	-				Gebremedhin and Swinton (2003)
S/SB	-		+					Gebregziabher et al. (2013); Tesfaye et al. (2014); Teshome et al. (2016)
S/SB		+	+	+	+	+	-	Demeke (2003); Mengstie (2009); Tesfaye et al. (2014); Teshome et al. (2016)
S/SB		+	+	-		+	+	Mengstie (2009); Schmidt and Tadesse (2012); Wossen et al. (2013)
DD	+	-		-			+	Benin and Pender (2001)
GT				+			+	Gebregziabher et al. (2013)
MF		+		-	+	+	+	Bekele and Drake (2003); Deressa et al. (2009); Schmidt and Tadesse (2012); Wossen et al. (2013)
MF		-	-	+			+	Schmidt and Tadesse (2012)
MF	+	+	+	+			+	Asrat et al. (2004); Gebremariam and Edriss (2010)
C/FYM		-						Pender and Gebremedhin (2006)
C/FYM	+	-	+	+		+		Kassie et al. (2009b); Pender and Gebremedhin (2006)
FYM		+		+			+	Gebremedhin et al. (2003)
FYM							+	Benin (2006)
FYM						-	+	Teklewold et al. (2013)
TP		+	+	+			+	Gebregziabher et al. (2013); Holden et al. (2004); Mengstie (2009)
TP	+	+						Benin and Pender (2001)
TP		+	+					Gebremedhin and Swinton (2003)
MT		+		-		+	+	Pender and Gebremedhin (2006); Benin (2006)
MT	+	+	+				+	Kassie et al. (2009b)

PRACTICE	DISTANCE TO MARKET[c]	LAND SIZE[b]	LAND TENURE[b]	FARM SIZE[b]	PLOT SIZE[b]	PLOT SLOPE[d]	HERD SIZE[a]	SOURCE
MT		+		+			-	Benin (2006)
IC		-						Pender and Gebremedhin (2006)
CP		-		+				Pender and Gebremedhin (2006)

MT = minimum tillage, **IC** = intercropping, **CP** = contour ploughing, **TP** = tree planting, **FYM** = farmyard manure, **C** = compost, **GT** = gully treatment, **MF** = mixed farming, **DD** = drainage ditch, **S/SB** = soil/stone bund, **SB** = stone bud, **HH** = household. The letters [a, b, c, d] stand for socio-economic, farm level, institutional and biophysical factors, respectively.

Table 4 The effect of different socioeconomic characteristics on the adoption of different agricultural practices that have potential to increase soil carbon in both the short and long term in **Kenya**

PRACTICE	AGE OF THE HH HEAD[a]	EDUCATION[a]	GENDER[a]	HOUSEHOLD SIZE[a]	OFF-FARM INCOME[a]	FARM SIZE[b]	ECONOMIC ACTIVITY[a]	SOCIO-CULTURAL[a]	SOURCE
IDT		+	+		-	+	-		Kebebe et al. (2017)
NRM		+	+		+	+	-		Ng'ang'a et al. (2016a)
CA		+	+			+			Wainaina et al. (2016)
CA		+				-		-	Aboud et al. (1996)
SB		+	+			-			Millington et al. (1989); Wainaina et al. (2016)
ST		+	+			+			Wainaina et al. (2016)
SWC				+				-	Kassie et al. (2015); Ndiritu et al. (2014)
WS/C	-	+	+		+	+			Marenya and Barrett (2007)
FYM	-	+	+		+	+			Marenya and Barrett (2007)
FYM	+	+			-	+		+	Kassie et al. (2015); Mugwe et al. (2009); Waithaka et al. (2007)
FYM			+			-			Mutoko et al. (2014); Ndiritu et al. (2014)
Mulching	-	+	+		+	+			Marenya and Barrett (2007)
Enclosure		+			+		+		Wairore et al. (2016)
Agroforestry		+				+			Noordin et al. (2001); Nyaga et al. (2015)
CC	-/+	+	+						Murage et al. (2015); Mwangi et al. (2015)
PP			+						Murage et al. (2015)
SLM		+							Mganga et al. (2015)
CCA	+	+	-			+			García de Jalón et al. (2015)
CD	-					+			Kassie et al. (2015)
MT	+					-			Kassie et al. (2015)

PRACTICE	AGE OF THE HH HEAD[a]	EDUCATION[a]	GENDER[a]	HOUSEHOLD SIZE[a]	OFF-FARM INCOME[a]	FARM SIZE[b]	ECONOMIC ACTIVITY[a]	SOCIO-CULTURAL[a]	SOURCE
IV	-	+	+			-			Kassie et al. (2015); Mutoko et al. (2014); Ndiritu et al. (2014); Ogada et al. (2014)
IV		-		+		+			Simtowe and Muange (2013)
IV		-				-			Thuo et al. (2014)
IF	-	+	+		+	-		+	Kamau et al. (2014); Kassie et al. (2015); Mutoko et al. (2014); Ogada et al. (2014)
IF		+		-	+	+			Mugwe et al. (2009); Waithaka et al. (2007); Freeman and Omiti (2003)
SFM					+				Chikowo et al. (2014)
CPR						-			Ndiritu et al. (2014)
Intercropping		-	-			-			Ndiritu et al. (2014)
MT		-	+			-			Ndiritu et al. (2014)
EC		+			+				Kamau et al. (2014)
BT		+			+	+			Mwirigi et al. (2009)
TF		+				+		+	Pisanelli et al. (2008)
Terracing		+			+				Millington et al. (1989)
SC		+			+				Millington et al. (1989)
CF		+			+				Millington et al. (1989)
DI		+						+	Kulecho and Weatherhead (2006)
IPM		+							Muriithi et al. (2016)
NPG						-			Mutoko et al. (2014)

Table 4 The effect of different socioeconomic characteristics on the adoption of different agricultural practices that have potential to increase soil carbon in both the short and long term in **Kenya** (**cont'd**)

PRACTICE	LABOR[a]	FARMING SEASON[b]	PLOT SIZE[b]	NO. OF CROPS /LIVESTOCK[b]	LAND TENURE[b]	OUTPUT[b]	FARMING EXPERIENCE[b]	RISK[c]	SUBSIDY[c]	PRICE[c]	SOURCE
IDT	+										Kebebe et al. (2017)
NRM	+			+							Ng'ang'a et al. (2016a)
CA	+			+				-			Tesfaye et al. (2014); Wainaina et al. (2016)
CA					-		+				Aboud et al. (1996)
CA						+					Jaleta et al. (2013)
SB	+			+				-			Wainaina et al. (2016)
SB					+		+	+	+		Millington et al. (1989)

PRACTICE	LABOR[a]	FARMING SEASON[b]	PLOT SIZE[b]	NO. OF CROPS /LIVESTOCK[b]	LAND TENURE[b]	OUTPUT[b]	FARMING EXPERIENCE[b]	RISK[c]	SUBSIDY[c]	PRICE[c]	SOURCE
ST	+		+	+	+			-			Wainaina et al. (2016)
SWC			+		+						Kassie et al. (2015)
SWC					-						Waswa et al. (2002)
WS/C	+			+	+						Marenya and Barrett (2007)
FYM				+							Marenya and Barrett (2007); Ndiritu et al. (2014)
FYM	+		-	+	+						Kassie et al. (2015)
Mulching	+			+	+						Marenya and Barrett (2007)
Enclosure				+	+		+				Wairore et al. (2016)
Agroforestry					+		+				Kabubo-Mariara (2014); Nyaga et al. (2015)
CCA	-										García de Jalón et al. (2015)
CD			-								Kassie et al. (2015)
IV			+								Kassie et al. (2015); Ndiritu et al. (2014)
IV			+		+	+					Ogada et al. (2014)
IF			+	+	+	+	+				Freeman and Omiti (2003); Kamau et al. (2014); Ndiritu et al. (2014); Ogada et al. (2014)
SA	+	-		+	-					-	Kamau et al. (2014)
CR	-		+								Mugwe et al. (2014); Ndiritu et al. (2014)
Intercropping			+								Ndiritu et al. (2014)
MT	-		+								Kassie et al. (2015); Ndiritu et al. (2014); Okeyo et al. (2014)
EC		-		+	-					-	Kamau et al. (2014)
Terracing	-				+		+	+	+		Millington et al. (1989)
Terracing					+						Kabubo-Mariara (2014)
SC					+		+	+	+		Millington et al. (1989)
CF					+		+	+	+		Millington et al. (1989)

Table 4 The effect of different socioeconomic characteristics on the adoption of different agricultural practices that have potential for increasing soil carbon in both the short and long term in **Kenya** (**cont'd**)

PRACTICE	CREDIT ACCESS[c]	INFORMATION ACCESS[c]	EXTENSION SERVICES[c]	MARKET ACCESS[c]	GROUP MEMBERSHIP[c]	SLOPE[d]	SOURCE
IDT		+	+	+			Kebebe et al. (2017)
NRM	+	+		+			Ng'ang'a et al. (2016a)
CA		+	+				Aboud et al. (1996); Jaleta et al. (2013); Wainaina et al. (2016)
SB			+				Wainaina et al. (2016)
ST			+			+	Wainaina et al. (2016)
SWC	+			-		-	Ndiritu et al. (2014)
FYM				-			Waithaka et al. (2007)
FYM			+			+	Ndiritu et al. (2014)
Enclosure	+						Wairore et al. (2016)
Agroforestry	+		+	-			Kabubo-Mariara (2014); Noordin et al. (2001)
PP		+		+			Murage et al. (2015)
SLM	+	+	+	+	+		Gebreselassie et al. (2015)
CD				+			Kassie et al. (2015)
IV	+	+		-	+		Kassie et al. (2015); Mogaka et al. (2014); Ndiritu et al. (2014); Ogada et al. (2014); Thuo et al. (2014)
IF			+	-		-	Ndiritu et al. (2014); Kamau et al. (2014); Waithaka et al. (2007)
IF				+	+		Freeman and Omiti (2003); Kassie et al. (2015)
SA				-			Kamau et al. (2014)
CPR	+						Ndiritu et al. (2014)
Intercropping			+		+		Ndiritu et al. (2014)
MT	+		+		+		Ndiritu et al. (2014)
Terracing			-	-			Kabubo-Mariara (2014); Millington et al. (1989)
DI			+	-			Kulecho and Weatherhead (2006)
IPM				+			Muriithi et al. (2016)
FLC				-			Were et al. (2014)
CE				-/+			Were et al. (2014)

IDT = improved dairy technology, **NRM** = natural resource management, **SB** = soil bunds, **ST** = stone terraces, **SWC** = soil and water conservation, **CA** = conservation agriculture, **WS/C** = wood shrub contours, **FYM** = farmyard manure, **CC** = cover crops, **PP** = push and pull technology (companion cropping), **SLM** = sustainable land management, **CCA** = climate change adaptation, **TF** = tree fallow, **DI** = drip irrigation, **NPG** = Napier grass strips, **CD** = crop diversification, **MT** = minimum tillage, **IV** = improved variety, **IF** = inorganic fertilizer, **SFM** = soil fertility management, **CR** = crop residue, **FLC** = forest shrub land conversion, **GC** = grassland conversion, **CE** = crop expansion, **BT** = biotechnology, **EC** = erosion control, **IPM** = integrated pest management, **CF** = contour farming, **SC** = strip cultivation, **SA** = soil amendments, **TWI** = topographic wetness index. [a, b, c, d] stand for socioeconomic, farm-level, institutional, and biophysical factors.

In Western Kenya, older farmers exhibit a lower likelihood of adopting fertilizer (Table 4). Mwangi et al. (2015) also show mixed effects of age on the adoption of cover crops. Farmers whose age ranges from 36 to 45 and 46 to 55 years are less likely and more likely to adopt cover crops, respectively, than those who are over 55 years. In Ethiopia, Anley et al. (2007) also found a negative and significant effect of age on the adoption of improved soil bunds. A similar effect of age is observed for conservation tillage (Kassie et al., 2009a). This could be due to the risk-averse nature of young farmers (Marenya and Barrett, 2007) compared with older farmers who tend to have a short planning horizon (Heyi and Mberengwa, 2012). This clearly indicates that it is very difficult to single out a uniform influence by some of the socioeconomic factors such as age of the household head on adoption (Nkonya et al., 2011).

Gender of the household head

The gender of the household head has varied effects (i.e., both negative and positive) on the adoption of carbon-enhancing soil practices in both countries (Kassie et al., 2009b). For example, male-headed households had a negative and significant influence on the adoption of cover crops and the use of compost in Kenya and Ethiopia, respectively; which could be attributed to men's perception on the usefulness of these practices (Mwangi et al., 2015). This observation is sustained by García de Jalón et al. (2015), who observed that male-headed households in Makueni (Eastern Kenya) generally have a skeptical response to climate change, which is a behavioral barrier in the adoption of climate change strategies. Male-headed households are likely to adopt fertilizer and manure (including compost) in both countries (Kassie et al., 2009b; Marenya and Barrett, 2007; Ogada et al., 2014), but the opposite is true for their female counterparts. This could be explained by the resource-constrained nature of female-headed households, which undermines their ability to mobilize labor. This finding resonates with those in the western and eastern highlands where men are more likely to apply animal manure on their farms (Ndiritu et al., 2014), while women tend to manage soils with lower fertility.

Education of the household head

In both Kenya and Ethiopia, the effect of farmers' education status is either positive or negative. A positive impact on the adoption of technologies (e.g., conservation measures) suggests that it facilitates communication of the key messages on interventions (Noordin et al., 2001). Moreover, education enhances farmers' insight into the available options for adapting to and better understanding the importance of maintaining soil fertility (e.g., via the use of fertilizer) (Kamau et al., 2014; Ogada et al., 2014; Waithaka et al., 2007). Education, therefore, increases the propensity for making land-related investment (Ketema and Bauer, 2012). Some soil carbon-enhancing practices (such as intercropping and minimum tillage) may require certain skills and knowledge to implement, manage, and maintain. For such practices, a high level of education tends to facilitate their adoption, and vice versa. This finding suggests that any attempt to improve the adoption of intercropping and minimum tillage as soil carbon-enhancing technologies among farmers in a given region may need to make a provision for some education (albeit low).

A negative effect of education on the adoption of soil carbon-enhancing technologies is because education improves the ability of the household member to analyze data, including calculating the costs and benefits of different practices. Practices that seem less profitable are less appealing for adoption. Education also improves access to off-farm income-generating activities, thereby making farmers reluctant to adopt practices that enhance soil carbon (Adimassu et al., 2016).

Household size

In most of the studies reviewed, household size exerts a positive influence on the adoption of soil carbon-enhancing practices among farmers (Gebremariam and Edriss, 2010; Kassie et al., 2015; Ndiritu et al., 2014; Schmidt and Tadesse, 2012; Simtowe and Muange, 2013; Teshome et al., 2016). This could be because most of these practices, for example, the construction and maintenance of soil and water conservation measures such as soil/stone bunds, are labor intensive. Labor is crucial in the adoption of SLM practices, especially during installation and for maintenance (Millington et al., 1989). Consequently, households with more members (i.e., economically active household members) can invest easily in soil carbon-enhancing practices (Kassie et al., 2015; Ndiritu et al., 2014; Simtowe and Muange, 2013; Tadesse and Belay, 2004). This is because family labor can be channeled to labor-intensive soil and land improvement practices. Small-sized households are more likely to adopt less labor intensive practices such as the use of fertilizer (Freeman and Omiti, 2003) compared with manure or compost.

Nevertheless, labor availability has varied effects on the adoption of soil carbon-enhancing practices. For example, the use of manure increases significantly with the availability of family labor but declines with an increase in casual labor (Waithaka et al., 2007). The implication of this is that, although manure application is a labor-intensive process, when collection and application are done using casual laborers, a cost element is introduced and this acts as an additional constraint (Kamau et al., 2014).

Income

The adoption of almost all the carbon-enhancing practices requires a cash outlay for the acquisition of inputs and labor. The positive effect of off-farm income on the adoption of soil bunds, mixed farming, and tree planting indicates that it facilitates the adoption of practices that require some cash outlay for implementation. Cash from off-farm income may facilitate the initial implementation of an agricultural or sustainable land practice through the purchase of seed and seedlings in the case of crops and agro-forestry, respectively. In the case of soil/stone bunds, however, cash income is used largely for implementation and maintenance. Low income among farmers is, therefore, a major limiting factor in the adoption of agricultural technologies that enhance soil carbon. In Western Kenya, the adoption of soil fertility management, soil erosion control, and the use of inorganic fertilizer is more common among wealthy farmers than among poor farmers (Chikowo et al., 2014; Kamau et al., 2014; Mwirigi et al., 2014). The importance of income cannot, therefore, be overemphasized in that it improves farmers' livelihoods by relaxing the capital constraint and it stimulates farm productivity by facilitating the adoption of improved technologies (Ng'ang'a et al., 2016a), especially in areas with a poorly developed credit market (Ketema and Bauer, 2012).

Nevertheless, involvement in off-farm income-generating activities has a negative impact on the adoption of technologies because it diverts labor from on-farm activities (Gebregziabher et al., 2013; Heyi and Mberengwa, 2012). Farmers who are involved in off-farm activities are likely to encounter time and labor constraints for investing in intensive SLM practices such as soil/stone bunds and the use of manure (Waithaka et al., 2007). These findings suggest that farm households need to prioritize their needs before pursuing income-related objectives. The implication is that, when introducing new technologies, there is a need for development partners to focus on opportunity cost aspects.

Farmers' experience

The duration for which a household has been growing trees (i.e., experience) positively influences the density and diversity of tree species, and hence the sequestration of soil carbon. The same applies to fertilizer use, whereby farmers who have used it over a long period are likely to continue using it. This could be because of technical information and economies of scale that farmers acquire over time (Freeman and Omiti, 2003; Nyaga et al., 2015).

Livestock holding

Livestock are generally considered as assets to farm households (e.g., Ng'ang'a et al., 2016b) that could be either used in the production process or exchanged for cash or other productive assets that could help in influencing the adoption of soil carbon-enhancing practices (Adimassu et al., 2016). Nevertheless, the effects of livestock holding on the adoption of soil carbon-enhancing practices are inconsistent. This is because some farmers' livelihoods depend on livestock production and they may want to invest in measures reducing soil erosion and land degradation. In arid and semi-arid areas (ASALs), for example, rearing of livestock is the main source of livelihoods, and maintenance of high-quality pastures may help to improve resilience for rangeland. In such areas, households may be motivated to adopt strategies that reduce migration (and hence land degradation) through maintenance of enclosures aimed to improve livestock productivity and management (Wairore et al., 2016).

3.2.2 Farm-level or plot characteristics

Arable land (farm) size

Farm size has a mixed effect on the adoption of different soil carbon-enhancing practices in both Kenya and Ethiopia. For example, large plot size has a positive effect on the adoption of intercropping, soil and water conservation, minimum tillage, and the use of fertilizer and manure (Mugwe et al., 2014; Ogada et al., 2014). The positive effect of farm size on the different soil carbon-enhancing practices (i.e., soil bunds, soil/stone bunds, compost, farmyard manure, and gulley treatment) suggests that these practices may not be strictly scale neutral or that the opportunity costs facing farms vary systematically by farm size. The positive effect of farm size could also be because farm size is highly correlated with household wealth (Ng'ang'a et al., 2016a), which may help in easing the financial constraint since land could be used as collateral. The negative effect of land size on the adoption of various soil carbon-enhancing practices is because, when land availability is not a problem, farmers may not worry about soil erosion and degradation, thereby reducing their propensity to invest in soil carbon-enhancing practices (Adimassu et al., 2016; Gebremedhin and Swinton, 2003; Hagos and Holden, 2006; Pender and Gebremedhin, 2006). Diminishing farm size may hinder the adoption of practices that have potential to sequester carbon (Teshome et al., 2016). For example, Thuo et al. (2014) show that small farm size negatively affects the adoption of improved varieties of groundnuts, while households with large farms are likely to adopt the use of manure and tree fallows (Mugwe et al., 2009; Pisanelli et al., 2008). These findings suggest that households with larger landholdings have an advantage associated with economies of scale, thereby investing in technologies that improve soil fertility and hence agricultural productivity and income (Kebebe et al., 2017).

Land tenure

By drawing a parallel from the reviewed studies in Ethiopia and Kenya, it is apparent that the effects of different socioeconomic factors vary under different types of land tenure. For example, Ogada et al. (2014) and Wainaina et al. (2016) note that households with tenure security have a higher probability of adopting the use of inorganic fertilizer, stone terracing, and manure. However, this is not always the case as tenure security has also been shown to have a negative and significant influence on the use of inorganic fertilizer and zero tillage. This could be because of differences in decision-making processes as influenced by the type of land ownership (i.e., whether the land is rented or owned) (Millington et al., 1989). Technologies that demand high reliance on machinery and agro-chemicals for maintenance result in spiraling expenditure and, given the difficulty in obtaining sufficient income for employing laborers, they are prohibitive (Millington et al., 1989). However, farmers who own land could use their title deeds as collateral to obtain credit.

The observed differences in the effect of socioeconomic factors on the adoption of soil carbon-enhancing practices could be associated with the type of tenure systems (i.e., farm or some plots being owned while others are in-rented). Households with secure land tenure are more likely to adopt long-term soil conservation measures such as stone terraces and agro-forestry (Gebremedhin and Swinton, 2003; Nyaga et al., 2015), and vice versa. For example, in cases in which farmers own land, and possess the title deeds, their land-use rights are well established on the land and they can, therefore, invest in long-term improvement.

Slope of plots

The results show that farmers invest more in physical practices that enhance soil carbon in plots with steep slopes, because of the more obvious erosion risks and rates of loss of soil fertility than in plots on gentle slopes. For instance, the adoption of stone bunds, terraces, soil bunds, and minimum tillage is more likely on steep slopes for preventing soil erosion and fertility loss (Gebremedhin and Swinton, 2003; Wainaina et al., 2016). Ndiritu et al. (2014) also found that soil and water conservation and fertilizer are less likely to be used on flat plots. However, soil conservation measures and the use of manure are likely to be applied on slopes (Anley et al., 2007; FAO, 2016).

3.2.3 Institutional, market access, socio-cultural, and biophysical factors

Credit, information, and extension

Access to credit accelerates the adoption of SLM practices such as agroforestry, soil and water conservation, and minimum tillage (Ndiiri et al., 2013; Noordin et al., 2001; Recha et al., 2015). This is because credit helps households in relaxing binding financial constraints, thereby enabling farmers to acquire inputs (Abate et al., 2016). Receiving quality information (e.g., through radio, television, and extension officers) on new technologies can help in narrowing the gap between what is perceived by households and the reality (Bekele and Drake, 2003; Murage et al., 2015). Consequently, access to information has a positive effect on the adoption of the use of soil erosion prevention strategies, and inorganic fertilizer (Bekele and Drake, 2003; Mogaka et al., 2014; Ogada et al., 2014; Thuo et al., 2014). Access to extension services has a positive influence on the adoption of inorganic fertilizer, manure, soil bunds, terraces, and conservation agriculture (Jaleta et al., 2013; Kulecho and Weatherhead, 2006; Ndiritu et al., 2014). This could be because of the better understanding of the new technologies, and hence their diffusion.

Market access

Access to input and output markets by households is usually associated with some transaction costs, but as to whether these costs have a positive or negative effect on the adoption of technology depends on other factors such as distance or the state of infrastructure. For example, improved access to markets is associated with the adoption of fertilizer use (Freeman and Omiti, 2003; Murage et al., 2015; Recha et al., 2015), while poor market access tends to constrain fertilizer use (Kassie et al., 2015; Ogada et al., 2014; Waithaka et al., 2007). An increase in the price of fertilizer has a negative effect on the adoption of inorganic fertilizer (Kamau et al., 2014), and this may lead to the use of alternative measures such as manure. In order to curb the negative effect of price on fertilizer use, subsidies are sometimes introduced and they play a significant role in the adoption of inorganic fertilizer (Millington et al., 1989).

Socio-cultural factors and group membership

Social networks among farmers play a crucial role in enhancing learning, and hence the adoption of new technologies such as the use of fertilizer and manure (Thuo et al., 2014). Social networks aid the flow of information and can (albeit indirectly) bring benefits such as access to credit (Ng'ang'a et al., 2016a) and information on access to specific inputs such as manure. Farmers who are organized in groups are more likely to adopt improved varieties and fertilizer. This is because groups are a focal point for information exchange and capacity building, and a form of social capital (Ng'ang'a et al., 2016b). Farmers who are organized in groups, therefore, have the advantage of meeting technical experts who can inform them about the consequences of soil erosion. Improved access to information and social capital benefits can thus enhance technology adoption (Kassie et al., 2015; Mogaka et al., 2014). Nevertheless, Ketema and Bauer (2012) observed a negative effect of membership in organizations on the adoption of stone terraces probably because the group's focus was on short-term land management strategies such as the use of fertilizer. Community culture could act as an impediment to the adoption of some practices. For example, pastoralists have been noted to form the bulk of discontinuers of soil conservation methods (Kulecho and Weatherhead, 2006). This could be because they are not used to arable farming and, therefore, find soil conservation measures laborious.

Season

Farmers are most likely to use fertilizer during the main season because they maximize returns on fertilizer when rainfall is abundant (Kamau et al., 2014). In line with theoretical expectations, smallholders indeed follow an economic logic so that their primary goal is to maximize output. Therefore, an expected increase in output is likely to increase the adoption of fertilizer use (Ogada et al., 2014). Increased output from the farm, in turn, increases the use of crop residues for soil fertility management (Jaleta et al., 2013).

3.3 Review summary

The review of the socioeconomic factors that influence or constrain the adoption of practices that enhance soil carbon sequestration (i.e., Tables 3 and 4) showed that the papers reviewed contain several inconsistent results. To this end, an attempt is hereby made to summarize the review results and to identify any distinct pattern among the factors that constrain or facilitate the adoption of soil carbon-enhancing practices (Table 5). This was achieved by grouping all the variables into categories that are easy to understand by policymakers and a wider non-academic audience. As stated previously, both agricultural management practices and sustainable land management practices that enhance the sequestration of soil carbon or that mitigate the loss of carbon were considered as soil carbon-enhancing practices. This is because the adopted agricultural practices can influence soil carbon either by mitigating losses to the atmosphere or by increasing the accumulation of carbon stock.

Table 5 Summarized frequencies of the analyzed variables that influence or constrain the adoption of soil carbon-enhancing practices in **Ethiopia**

FACTORS INFLUENCING OR CONSTRAINING	SHORT-TERM SOIL CARBON-ENHANCING PRACTICES		LONG-TERM SOIL CARBON-ENHANCING PRACTICES		ALL PRACTICES (%)	
	(+)	(-)	(+)	(-)	(+)	(-)
Age of the household head	40	60	38	62	39	61
Education of the household head	60	40	69	31	64	36
Gender of the household head	57	43	77	23	67	33
Household size	71	29	20	80	46	54
Economic activity	78	22	100	0	89	11
Off-farm income	56	44	58	42	57	43
Credit	85	15	60	40	72	28
Access to information	100	0	100	0	100	0

FACTORS INFLUENCING OR CONSTRAINING	SHORT-TERM SOIL CARBON-ENHANCING PRACTICES		LONG-TERM SOIL CARBON-ENHANCING PRACTICES		ALL PRACTICES (%)	
Extension services	85	15	73	27	79	21
Distance to the market	100	0	57	43	79	21
Land size	69	31	71	29	70	30
Land tenure	83	17	25	75	54	46
Farm size	67	33	50	50	58	42
Plot size	100	0	100	0	100	0
Plot slope	75	25	100	0	88	13
Herd size	91	9	42	58	66	34

The results in Tables 5 and 6 show summarized frequencies of the analyzed variables that influence or constrain the adoption of soil carbon-enhancing practices in both Ethiopia and Kenya, respectively. The results show that, although most of the household- and plot-level variables have similar trends for both the long-term and short-term results in both countries, some inconsistencies were observed. In Ethiopia, for example, 71% of the studies showed a positive relationship between household size and farmers' adoption of short-term soil carbon-enhancing practices. However, 80% of the studies showed a negative relationship between household size and the adoption of long-term soil carbon-enhancing practices.

Table 6 Summarized frequencies of the analyzed variables that influence or constrain the adoption of soil carbon-enhancing practices in **Kenya**

FACTORS INFLUENCING OR CONSTRAINING	SHORT-TERM SOIL CARBON-ENHANCING PRACTICES		LONG-TERM SOIL CARBON-ENHANCING PRACTICES		ALL PRACTICES (%)	
	(+)	(-)	(+)	(-)	(+)	(-)
Age of the household head	50	50	50	50	50	50
Education of the household head	83	17	100	0	92	8
Gender of the household head	92	8	75	25	83	17
Household size	50	50	100	0	75	25
Off-farm income	86	14	100	0	93	7
Farm size	55	45	75	25	65	35
Economic activity	33	67	100	0	67	33
Socio-cultural aspects	75	25	50	50	63	38
Household labor	73	27	50	50	61	39

FACTORS INFLUENCING OR CONSTRAINING	SHORT-TERM SOIL CARBON-ENHANCING PRACTICES		LONG-TERM SOIL CARBON-ENHANCING PRACTICES		ALL PRACTICES (%)	
Farming season	0	100	0	0	0	100
Plot size	75	25	67	33	71	29
No. of crops/livestock	100	0	100	00	100	0
Land tenure	79	21	75	25	77	23
Farming experience	100	0	0	0	100	0
Risks	43	57	0	0	43	57
Subsidy	100	0	0	0	100	0
Credit access	100	0	100	0	100	0
Information access	100	0	100	0	100	0
Extension services	91	9	100	0	95	5
Market access	50	50	40	60	45	55
Group membership	100	0	100	0	100	0
Plot slope	67	33	100	0	83	17

Compared with the results presented in Tables 3 and 4, the results in Table 5 showed a clearer pattern of the effect of different factors on the adoption of soil carbon-enhancing practices. For instance, the following factors (plot size, plot slope, land tenure) related to land/farm are in general positively related to the adoption of soil carbon-enhancing practices in both Kenya and Ethiopia. This shows that farmers with large plot size, whose farm is situated on a slope, and those with land tenure (i.e., a title deed) are more likely to adopt soil carbon-enhancing practices than those whose plot size is small, whose farm is situated on a flat area, and those without a title deed. Similarly, the education level and gender of the household head, off-farm income, household size, and access to information and extension services are in general positively related to the adoption of soil carbon-enhancing practices in both Kenya and Ethiopia. This is because large household size ensures that sufficient labor is invested in a practice, while a high level of education enables the household to process information (including likely benefits) quickly, hence facilitating the adoption of a practice. The positive effect of off-farm income implies that farmers with higher financial capital invested more in soil carbon-enhancing practices than farmers with lower off-farm income. Farmers with better service provision (i.e., extension support) also invest more in soil carbon-enhancing practices.

Whereas the results in Table 5 show a better consolidation than the ones in Tables 3 and 4, a more detailed analysis could help to simplify the presentation even further. However, the results clearly show that the adoption of soil carbon-enhancing practices is mainly driven by factors that increase household investment capacity (i.e., off-farm income and education) and those that act as incentives (i.e., land tenure) for adoption. The capacity to invest and the incentives to adopt soil carbon-enhancing practices are, in turn, affected by the support provided to the farmers (e.g., extension services, access to markets and credit).

Photo: Georgina Smith/CIAT

4. Determinants of the adoption of SLM practices that enhance soil carbon in Kenya and Ethiopia

4.1 Household characteristics in Kenya and Ethiopia

The descriptive results for SLM practices as analyzed, using data from the WOCAT database for Kenya and Ethiopia, reveal the wealth status, role of gender in household decisions, market orientation, income levels, land size, access to technical assistance, and weighed costs-benefits. The results, which differ slightly between the two countries, point out the capacity of these households in adopting SLM technologies. Detailed results are summarized in Appendix 2 (Tables A7 and A8) and Appendix 3 (Tables A9 and A10) for Kenya and Ethiopia, respectively.

4.2 Factors influencing adoption in Kenya

The results in Table 7 show that the model explained 68% of the variations in the likelihood of households adopting SLM practices that enhance soil carbon sequestration. The estimated probability was greater than the chi-square value (probability > chi-square = 0.0000), implying that all the model parameters were jointly significant in explaining the dependent variable, indicating the goodness-of-fit of the model. The level of significance of each explanatory variable was tested using the null hypothesis, which states that explanatory variables have no significant effect on the adoption of SLM practices that enhance soil carbon sequestration. The p-values show the lowest level at which the null hypothesis can be rejected.

Table 7 Probit regression for determinants of the adoption of carbon sequestering SLM practices in **Kenya**

VARIABLE	COEFFICIENT	STD. ERROR	P-VALUE	MFX
Estimated cost of labor	-0.1e-04	o.7e-04	0.862	-0.000
Maintenance cost of labor	0.5e-05	0.5e-04	0.930	-0.5e-05
Maintenance cost of inputs	0.008	0.006	0.220	0.008
Production system	-0.479	0.974	0.624	-0.478

VARIABLE		COEFFICIENT	STD. ERROR	P-VALUE	MFX
Off-farm income					
	<USD 100	0 .922	0 .801	0.249	0.923
	USD 100-500	-9.423	1.956	0.000**	-9.423
	>USD 500	-1.518	0 .941	0.108	-1.517
Land size	-1.378	0.725	0.057	-1.378	
Technical assistance					
	Poor	-21.185	4.069	0.000**	-21.185
	Moderate	-3.982	1.944	0.041**	-3.982
	Good	-13.488	2.690	0.000**	-13.488
Strength		0.302	0.149	0.042**	0.302
Benefits-establishment costs (short run)		0.726	0.551	0.188	0.726
	Positive	-2.705	1.401	0.054	-2.705
	Very positive	-3.632	2.586	0.160	-3.632
	Negative	-10.412	1.7480	0.000**	-10.411
Market orientation					
	Mixed	11.571	2.656	0.000**	11.571
	Commercial	14.022	3.098	0.000**	14.022
Gender		0.752	0.317	0.018**	0.753

Log likelihood = -8.5172717; pseudo R2 = 0.6861; Mfx = marginal effects; probability > chi-square =0.000; ** stands for significant at the 5% level.

Market orientation had a positive and significant influence on the adoption of carbon-sequestering SLM techniques. Households that had a commercial market orientation were more likely to adopt such technologies. This could be because households whose production is commercially oriented seek to maximize output; hence, they are more likely to invest in practices that would improve output/yield. This finding is consistent with Gebreselassie et al. (2015), who found that households with access to both input and output markets had a higher number of adopted SLM technologies, as they represent a reduction in transaction costs and improved access to technical services. Gender was found to have a positive and significant influence on the adoption of SLM practices. Households in which decisions are jointly made were more likely to adopt carbon-sequestering SLM practices than households in which decisions are made separately by the female or male in the household. This implies that, when decisions are made jointly, there is an effectual management of resources that minimizes the costs and wastage of available resources, thus encouraging adoption. The variable strength that can be a proxy for the perception of the importance of the SLM practice was found to be positive and significant. This means that households that found an SLM practice of great significance were more likely to adopt the technology as opposed to those who found it not important.

Off-farm income had a negative and significant influence on the adoption of SLM practices whereby households in the middle-income category were less likely to adopt such practices. Our finding concurs with Waithaka et al. (2007) that households with lower income prioritize their needs before engaging in income-related activities, and this affects the adoption of some SLM practices. Although not significant, the coefficient for poorer households is positive, implying that, in smallholder settings, households have no option but to invest in SLM practices that are critical for food production. Contrary to studies that show a positive relationship between income and the adoption of technologies (Kamau et al., 2014; Marenya and Barrett, 2007; Ng'ang'a et al., 2016a), the negative coefficient for richer households could imply that wealthier households shift to activities with higher income, thus reducing investments in SLM practices. A contrary finding was observed in studies that disclosed a positive significance of access to technical assistance on the adoption of SLM practices (Jaleta et al., 2013; Kebebe et al., 2017; Noordin et al., 2001). A number of households have access that can be categorized as poor, moderate, or good, but the significance of access to technical assistance is negative. This could imply that the technical assistance accessible to the households is more inclined toward enhancing the quality of production. It could also be presumed that the source of technical assistance is not knowledgeable on modern SLM techniques. Millington et al. (1989), for instance, show that technical experts overlook other factors that influence soil conservation and tend to concentrate on issues such as soil, rainfall, topography, and cropping patterns.

The variable benefits and maintenance costs had a negative and significant influence on the adoption of SLM practices. Households whose assessment showed a negative benefit compared with costs in the short run were less likely to adopt the practices. High-impact SLM techniques are costly to maintain; hence, they ideally take a long time before benefits are realized. The implication of this is that households are resource constrained and are likely to adopt or use SLM techniques that would bring instant returns, and have a low maintenance cost in the short run. Such techniques, however, have low impacts in the long run. For instance, Savini et al. (2016) found that the adoption of phosphorus fertilizer by farmers in Kenya is profitable for increasing maize yield and biomass, with a marginal rate of return of above 100%, the standard minimum acceptable rate of return that is required for farmers to switch technologies. Guto et al. (2011) also show that the initial negative returns and high investment costs can be major limitations to the adoption of soil and water conservation measures by smallholder farmers. Surprisingly, though not significant, households that assessed benefits vs maintenance costs as positive had a negative correlation with adoption. This could mean that most households are not willing to spend their resources on implementing SLM practices but expect to benefit from them.

4.3 Factors influencing adoption in Ethiopia

The results in Table 8 show that the overall model explains 47% of the variations in the likelihood of households adopting carbon-sequestering SLM practices. The estimated probability was greater than the chi-square value (probability > chi-square = 0.0047). This implies that all the model parameters were jointly significant in explaining the dependent variable, indicating the goodness-of-fit of the model. The level of significance of each explanatory variable was tested using the null hypothesis that states that explanatory variables have no significant effect on the adoption of carbon sequestering SLM practices. The p-values show the lowest level at which the null hypothesis can be rejected.

Access to knowledge about the technology had a negative and significant effect on the adoption of SLM practices, suggesting that the households studied in Ethiopia lack knowledge of the existing technologies, which hinders adoption. Knowledge has been attributed to education level and training that equips farmers with the technical know-how required for undertaking conservation activities (Anley et al., 2007; Ketema and Bauer, 2012). This finding suggests a lack of effort by extension services in the diffusion of information on the adoption of conservation practices (Shiferaw and Holden, 1998).

Table 8 Probit regression results for determinants of the adoption of carbon-sequestering SLM practices in **Ethiopia**

VARIABLE		COEFFICIENT	STD. ERROR	P-VALUE	MFX
Knowledge of technology use	Low	-1.589	0.811	0.050***	0.000
	High	-0.949	0.823	0.249	0.000
Planting as an establishment activity		-1.161	0.569	0.041**	-0.223

VARIABLE		COEFFICIENT	STD. ERROR	P-VALUE	MFX
Establishment cost of inputs		0.1e-04	0.8e-05	0.156	0.2e-05
Establishment cost of tools & equipment		0.8e-04	0.002	0.670	0.1e-04
Pruning as a maintenance activity		0.898	0.751	0.232	0.181
Maintenance cost of inputs		0.021	0.008	0.006**	0.004
Maintenance costs		0.457	0.882	0.604	0.092
Gender		-0.082	0.674	0.903	-0.016
Wealth status		0.419	0.364	0.250	0.085
Population density		0.273	0.280	0.329	0.055
	Mixed	-2.468	1.397	0.077***	-0.391
	Subsistence	-1.549	1.161	0.182	-0.242
Off-farm income	<USD 100	0.144	1.013	0.887	0.028
	USD100-500	0.818	1.270	0.519	0.169
Rate of stabilization of dry-season stream flows		-0.042	0.071	0.555	-0.008
Rate of reduction in groundwater/river pollution		0.074	0.103	0.472	0.015
Benefits–establishment costs (short run)		0.212	0.252	0.401	0.043
Benefits–establishment costs (long run)		1.200	0.471	0.011**	0.243
Spontaneous adoption		0.017	0.214	0.938	0.003
Cheap labor		2.174	0.802	0.007*	0.439
Reduced cultivation land		-1.681	0.942	0.074***	-0.339
Other reasons		-3.191	1.116	0.004*	-0.645

NB: Log likelihood = -17.193824; probability > chi-square = 0.0047; Mfx = marginal effects; pseudo R^2 = 0.4679; *, **, *** stand for significant at 1%, 5%, and 10% level, respectively.

Planting as an establishment activity had a negative and significant effect on the adoption of SLM techniques. This was despite the fact that a majority of the households (80%) practiced this activity, implying that households prioritize plants on their farms as a staple or a field seasonal crop (for food security) and as food crops rather than as a carbon sequestration measure (Tadesse and Belay, 2004). The maintenance costs of inputs had a positive and significant effect on adoption, implying that these costs are relatively low and easily afforded by a majority of the households (including the poor). The introduction of land redistribution and credit programs in Ethiopia also promotes the intensity of input use by relaxing binding financial constraints (Benin and Pender, 2001).

Households with a mixed market orientation were less likely to adopt SLM practices. This could mean that, as much as production is for both commercial and mixed purposes, farmers focus mainly on meeting their food needs while commercialization is dependent on surplus. The positivity of benefits vs costs in the long run increased the probability of adopting SLM techniques.

This could be because SLM practices incur a lot of costs during establishment, whereas the benefits are realized afterward. This finding suggests that the practices implemented by households have higher benefits in the long run; hence, farmers are willing to take the risk of adopting and implementing them as they wait for the returns. However, even in cases in which farmers may perceive some benefits from a technology, its adoption is also determined partly by land tenure. This is because land tenure affects household investment behavior, especially for costly practices (Deininger and Jin, 2006).

Cheap labor has a positive and significant effect on the adoption of SLM practices. A unit increase in cheap labor increases the probability of adopting SLM technologies by about 0.5. This could mean that some SLM practices are labor intensive, and hence the establishment of such techniques is prohibitive, especially with limited labor. Therefore, households with access to cheap labor are more likely to adopt such techniques than those without access. The adoption of some SLM and conservation measures is laborious in nature. For such practices, the scarcity of labor acts as an impediment to their adoption in Ethiopia.

A reduction in the area under cultivation had a negative and significant effect on the adoption of SLM practices. This implies that households have smaller land sizes that are sufficient only for production to sustain their livelihoods. Thus, as small land size reduces the probability of adopting such practices, this means that households with larger land sizes are more likely to adopt land conservation techniques than those with smaller land sizes. Evidence shows that farmers with larger land sizes have more resources and capacity to allocate part of their farms to conservation practices (Anley et al., 2007; Ng'ang'a et al., 2016a).

Photo: Georgina Smith/CIAT

5. Conclusions and recommendations

This report reviewed and synthesized past research in order to identify the factors that influence or constrain the adoption of soil carbon-enhancing practices in Kenya and Ethiopia. It also sought to identify the factors that influence the adoption of sustainable management practices that enhance soil carbon sequestration using secondary data in the WOCAT database. The overall goal was to provide evidence that can help to evolve thinking and policy prescriptions to improve the adoption of soil carbon-enhancing practices. The review has identified several socioeconomic factors that influence the adoption of these practices. Generally, the review and synthesis identified some factors that contribute in a major way to the slowed investment in soil carbon sequestration in Kenya and Ethiopia. These factors include farmers' capacity to adopt soil carbon-enhancing practices, incentives that farmers derive from investing in these practices, and the poor provision of services or conditions for motivating farmers to invest in these practices and/or technologies. Further, the analysis showed that net returns, knowledge/information on the technology in use, and market orientation were significant factors influencing adoption. Thus, our review and synthesis underscored the need for improving the capacity of farmers to adopt soil carbon-enhancing practices. To this end, strategies such as improving households' access to off-farm income-generating opportunities, credit, and training (on the value of soil carbon enhancement), and the provision of technical assistance can be used to improve the adoption of soil carbon-enhancing practices.

The analysis of the factors that influence or constrain the adoption of SLM practices that enhance soil carbon sequestration showed that, when farmers have low to moderate income, and the perceived benefits of the SLM technologies are low in the short run, farmers are not keen on adopting them. However, wealthy households have no problem in adopting such practices. This indicates that, among the poor households, soil-enhancing SLM practices may be given low priority if the benefits in the short run are perceived to be uncertain. As such, there is a need to look into ways that can boost farmer incentives to invest in soil carbon-enhancing practices, even for those whose benefits may not be forthcoming in the short run. In that way, long-term soil carbon-enhancing practices will also be adopted, thereby reducing risks such as those associated with land degradation in a given landscape. Alternatively, the introduction of cost-effective SLM practices that fit the needs of the market would be plausible.

The results of the factors influencing or constraining the adoption of soil carbon-enhancing SLM practices have also shown that, rather than searching for a general blueprint, appropriate strategies may differ from one location to another, depending on the local agro-ecological, socioeconomic, and market conditions. This review and synthesis also provide a basis for looking at the socioeconomic factors that affect the adoption of different technologies in different contexts, and as such open an avenue for identifying complementarities and trade-offs. This study sheds light to counter misconceptions that socioeconomic factors affect the adoption of carbon-enhancing technologies in either a strictly positive or strictly negative way. The importance of the different factors and the direction of influence vary depending on the nature of the technology. As such, there is a need for further analysis of how to create enabling conditions that can enhance the adoption of soil carbon sequestration practices in different regions and farming systems. This will provide more robust findings upon which targeted recommendations and economic incentives for improved adoption of different soil enhancing practices in different locations can be based. Moreover, such findings may help to design policies aimed at increasing the development and uptake of soil carbon-enhancing practices in Africa.

Limitation of the study

Most of the literature reviewed focuses on smallholder adoption of an individual practice rather than a comparison between different types of technologies in the same context. Consequently, it is very difficult to compare different technologies in the same context. Moreover, the data and methodologies used in many studies are not easily comparable.

Appendices

Table A1 Description of the main variables that were used in the modeling

VARIABLE NAME	VARIABLE DESCRIPTION
Level of technical knowledge required by field staff	The level of technical knowledge required by field staff to be able to guide farmers in implementing the technology appropriately (1 if the level is low, 2 for high, and 3 for moderate)
Level of technical knowledge required by land users	The level of technical knowledge required by land users in implementing the technology appropriately (1 if the level is low, 2 for high, and 3 for moderate)
Establishment activities *1. Cutting/slashing vegetation*	Variable confirming whether establishment activity involves cutting/slashing vegetation (1 if it does, 0 if it doesn't)
2. Planting vegetation	Variable indicating whether establishment activity involves planting vegetation (1 if it does, 0 if it doesn't)
3. Digging/excavating the ground and shaping soil	Variable indicating whether establishment activity involves digging or excavating and shaping soil to build structures (1 if it does, 0 if it doesn't)
4. Spreading crop residue	Variable indicating whether establishment activity involves spreading of crop residue (1 if it does, 0 if it doesn't)
5. Piling stones	Variable indicating whether establishment activity involves piling of stones (1 if it does, 0 if it doesn't)
6. Structure construction	Variable indicating whether establishment activity involves construction of structures (1 if it does, 0 if it doesn't)
Costs of establishment in labor (USD)	Total labor costs incurred by a farmer in establishing the technology
Costs of establishment in inputs (USD)	Total input costs incurred by a farmer in establishing the technology
Costs of tools and equipment (USD)	Total costs of tools and equipment incurred by a farmer in establishing the technology
Total establishment costs (USD)	Total costs of establishment of the technology
Maintenance activities *1. Addition of manure and fertilizer*	Variable indicating whether maintenance activity involves addition of manure and fertilizer (1 if it does, 0 if it doesn't)
2. Spraying biocides	Variable indicating whether maintenance activity involves spraying of biocides (1 if it does, 0 if it doesn't)
3. Pruning	Variable indicating whether maintenance activity involves pruning (1 if it does, 0 if it doesn't)
4. Cutting vegetation	Variable indicating whether maintenance activity involves cutting vegetation (1 if it does, 0 if it doesn't)
5. Spreading crop residue	Variable indicating whether maintenance activity involves spreading crop residue (1 if it does, 0 if it doesn't)
6. Planting vegetation	Variable indicating whether maintenance activity involves planting vegetation (1 if it does, 0 if it doesn't)
Costs of maintenance labor (USD)	Total labor costs incurred by a farmer in maintaining the technology
Costs of maintenance inputs (USD)	Total input costs incurred by a farmer in maintaining the technology

VARIABLE NAME	VARIABLE DESCRIPTION
Costs of tools and equipment (USD)	Total costs of tools and equipment incurred by a farmer in maintaining the technology
Total maintenance costs (USD)	The total costs of maintenance of the technology
Characteristics of land users applying the technology	Characteristics of land users implementing the technology based on the system of cultivation (1 for intensive land users, 2 for extensive land users, 3 where both apply)
Gender of the decision maker of the land users applying this technology	Gender of the decision maker of the land users applying this technology (1 if male, 2 if female)
Level of wealth of land users applying the technology	Level of wealth of land users applying the technology (1 if they're rich, 2 if they're middle-income earners, 3 if they're poor)
Population density of the land users applying the technology (persons/km^2)	Population density of the land users applying the technology in persons per square kilometer (1 for <10, 2 for 10-50, 3 for 50-100, 4 for 100-200, 5 for 200-500, 6 for >500)
Market orientation of users of this technology	The market orientation available to the land users of this technology (1 for mixed subsistence and commercial, 2 for subsistence, 3 for commercial)
Off-farm income of the users of this technology	Proportion of household income sourced from outside the farmer's or land user's farm (1 for <10%, 2 for 10-50%, 3 for >50%)
Land size	Total area of the farm owned or leased by a farmer or a land user in hectares (1 for <0.5, 2 for 0.5-2.0, 3 for 2-20, 4 for 20-100, 5 for >100)
Land ownership	An indicator variable for land tenure of the land on which the technology is being implemented (1 for individual titled, 2 for individual not titled, 3 for state owned, 4 for company, 5 for individual titled & individual not titled, 6 for communal)
Access to health services	The level of land users' access to health services (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to education	The level of land users' access to education (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to technical assistance	The level of land users' access to technical assistance (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to off-farm employment	The level of land users' access to off-farm employment (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to markets	The level of land users' access to markets (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to energy	The level of land users' access to energy (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to transportation system	The level of land users' access to transportation (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to clean water and sanitation	The level of land users' access to clean water and sanitation (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Access to financial services	The level of land users' access to financial services (0 for not stated, 1 for poor, 2 for moderate, 3 for good)
Socioeconomic impact on the rate of increase in food production	A socioeconomic variable for the effectiveness of the technology in increasing food production on a scale of 1 to 10
Socioeconomic impact on the rate of increase in fodder production	A socioeconomic variable for the effectiveness of the technology in increasing fodder production on a scale of 1 to 10

VARIABLE NAME	VARIABLE DESCRIPTION
Socioeconomic impact on the rate of increase in animal production	A socioeconomic variable for the effectiveness of the technology in increasing animal production on a scale of 1 to 10
Socioeconomic impact on the rate of decrease in risk of production failure	A socioeconomic variable for the effectiveness of the technology in decreasing the risk of production failure on a scale of 1 to 10
Socioeconomic impact on the rate of increased diversity of income sources	A socioeconomic variable for the effectiveness of the technology in increasing diversity of income sources on a scale of 1 to 10
Socioeconomic impact on the rate of increased fuelwood production	A socioeconomic variable for the effectiveness of the technology in increasing fuelwood production on a scale of 1 to 10
Socio-cultural impact on the rate of improvement in food security	A socio-cultural variable for the effectiveness of the technology in improving food security on a scale of 1 to 10
Socio-cultural impact on the rate of improvement in SLM/land degradation knowledge	A socio-cultural variable for the effectiveness of the technology in improving SLM knowledge on a scale of 1 to 10
Rate of reduction in downstream siltation	A variable for the effectiveness of the technology in reducing downstream siltation on a scale of 1 to 10
Rate of stabilization of dry-season stream flows	A variable for the effectiveness of the technology on a scale of 1 to 10
Rate of reduction of groundwater/river pollution	A variable for the effectiveness of the technology on a scale of 1 to 10
Socioeconomic constraint of adopting and scaling up	An indicator variable for the constraints of adopting and scaling up the technology
Strength	The strength of the technology in reducing soil loss from a farmland and/or improving land cover on the farm on a scale of 1 to 10
Benefits with the establishment cost in the short run	A variable comparing the benefits accrued from implementing the technology with the costs of establishment of the technology in the short run (1 for slightly positive, 2 for positive, 3 for very positive, 4 for negative, 5 for balanced/neutral)
Benefits with the establishment cost in the long run	A variable comparing the benefits accrued from implementing the technology with the costs of establishment of the technology in the long run (1 for slightly positive, 2 for positive, 3 for very positive, 4 for negative, 5 for balanced/neutral)
Benefits with the maintenance cost in the short run	A variable comparing the benefits accrued from implementing the technology with the costs of maintenance of the technology in the short run (1 for slightly positive, 2 for positive, 3 for very positive, 4 for negative, 5 for balanced/neutral)
Benefits with the maintenance cost in the long run	A variable comparing the benefits accrued from implementing the technology with the costs of maintenance of the technology in the long run (1 for slightly positive, 2 for positive, 3 for very positive, 4 for negative, 5 for balanced/neutral)
Households that have adopted the technology with external material support (μ = no information)	The total number of households that have adopted the technology in the area under study with incentives
Households that have adopted the technology with external material support in % (μ = no information)	The proportion of the households that have adopted the technology in the area under study with incentives
Households that have adopted the technology without external material support (μ = no information)	The total number of households that have adopted the technology in the area under study without incentives
% of the population with spontaneous adoption of technology without incentives	The proportion of the households that have adopted the technology in the area under study without incentives [(1 representing 0-10 (very weak), 2 for 11-50 (weak), 3 for 51-70 (moderate), 4 for 71-90 (strong), 5 for 91-100 (very strong)]
Reasons that could encourage adoption of the technology (cheap labor required)	A variable for the reasons encouraging the adoption of the technology based on cheap costs of labor (i.e., 1 for cheap labor, 0 for high costs of labor)

VARIABLE NAME	VARIABLE DESCRIPTION
Reasons that could encourage adoption of the technology (cheap inputs required)	A variable for the reasons encouraging the adoption of the technology based on cheap costs of inputs (1 for cheap input costs, 0 for high costs)
Reasons that could encourage adoption of the technology (it is applicable for long periods of time)	A variable for the reasons encouraging the adoption of the technology based on its sustainability (1 for sustainable, 0 for unsustainable)
Reasons that could encourage adoption of the technology (high benefits in returns/it is effective)	A variable for the reasons encouraging the adoption of the technology based on high returns obtained from implementing it (1 for high returns, 0 for low returns)
Reasons that could encourage adoption of the technology (saves time and money)	A variable for the reasons encouraging the adoption of the technology based on saving time and money (1 for it saves time and money, 0 for it doesn't)
Reasons that could discourage the adoption of the technology (high costs of labor/labor intensive)	A variable for the reasons discouraging the adoption of the technology based on high costs of labor (1 for high costs, 0 for low costs)
Reasons that could discourage the adoption of the technology (high costs of inputs)	A variable for the reasons discouraging the adoption of the technology based on high costs of inputs (1 for high costs, 0 for low costs)
Reasons that could discourage the adoption of the technology (less benefits)	A variable for the reasons discouraging the adoption of the technology based on less benefits or returns from implementing it (1 for less benefits, 0 for more benefits)
Reasons that could discourage the adoption of the technology (crop-animal conflict on residues)	A variable for the reasons discouraging the adoption of the technology based on crop residue trade-offs between spreading on the farm and feeding animals for it leads to conflict on residues (0 for it doesn't)
Reasons that could discourage the adoption of the technology (community conflicts)	A variable for the reasons discouraging the adoption of the technology based on community conflicts (1 for it leads to conflicts, 0 for it doesn't)
Reasons that could discourage the adoption of the technology (encourages pest infestation)	A variable for the reasons discouraging the adoption of the technology based on the ability of the technology in encouraging infestation of pests (1 for it encourages, 0 for it doesn't)
Reasons that could discourage the adoption of the technology (discourages machine operations)	A variable for the reasons discouraging the adoption of the technology as it discourages machine operations on the farm (1 for it discourages, 0 for it doesn't)
Reasons that could discourage the adoption of the technology (reduced cultivation land)	A variable for the reasons discouraging the adoption of the technology based on a reduction in cultivation land by the technology (1 for the tech reduces cultivation land, 0 for it doesn't)
Reasons that could discourage the adoption of the technology (dangerous shrubs)	A variable for the reasons discouraging the adoption of the technology as it involves dangerous shrubs that could hurt or poison users (1 for availability of dangerous shrubs, 0 for the technology lacking dangerous shrubs)
Reasons that could discourage the adoption of the technology (others)	A variable for other reasons discouraging the adoption of the technology
Description	The description of other reasons discouraging the adoption of the technology

NB: USD stands for United States Dollar

Table A2 Some selected SLM practices in Kenya and Ethiopia

PRACTICE CODES AS THEY APPEAR IN THE WOCAT DATABASE (www.wocat.net)	SLM TECHNOLOGY	COUNTRY WHERE PRACTICED	
		KENYA	ETHIOPIA
940	Small-scale conservation tillage	✓	
1740	Boundary hedgerows	✓	
1735, 974, 1387	Trash lines	✓	✓
1095	Double-dug beds	✓	
1569	Natural riparian vegetation to sustain a stable river bank	✓	
1581	Stone lines	✓	
1097	Water harvest	✓	
1244	Retention ditches	✓	
1323	Conservation agriculture	✓	
941	Conservation tillage for large-scale cereal production	✓	
1489	Pasture management through removal of *Commiphora*	✓	
1488	Gully rehabilitation	✓	
1486, 1537	Sand dams (Kitui)	✓	
1485	Retention ditch (Muranga)	✓	
1676	Nine maize pits	✓	
1096	Riverbed reclamation & silt trapping for sugarcane	✓	
1487	Water harvesting and enlarged structures	✓	
1484	Pitting (Machakos)	✓	
1094	Road runoff management (Nyeri)	✓	
507	Farmer-managed natural regeneration (FMNR)	✓	
1743	Rotational grazing	✓	
1320	Artificial grassed waterway	✓	
1318	Mulching	✓	
1567	Riparian forest to improve riverbank stabilization	✓	
1580	Keeping natural riparian vegetation and stabilizing riparian area with gabions (Naro Moru River)	✓	
1570	Trees in the riparian area as a protective and aesthetic advantage (Naro Moru River)	✓	

PRACTICE CODES AS THEY APPEAR IN THE WOCAT DATABASE (www.wocat.net)	SLM TECHNOLOGY	COUNTRY WHERE PRACTICED	
		KENYA	ETHIOPIA
1325	Cover crops	✓	
1324	Raised beds for onions	✓	
1326	Crop rotation	✓	
1322	Multi-storey gardens	✓	
1736	Woodlot	✓	
958	Push-pull integrated pest and soil fertility management	✓	
1559	Tree row and grass strip to sustain filtering	✓	
1483	Road runoff system (Mwingi)	✓	
1135	Planting bamboo and *Grevillea* for riparian land conservation	✓	
1558	Productive use of riparian area using Napier grass	✓	
1066	Chat ridge bund		✓
1059, 1389, 1076, 1546	Stone bund (Dejen, Haraghie, large semi-circular)		✓
1069	Earth checks for gully reclamation		✓
1075	Micro catchments and ponds		✓
1062, 1468, 1077, 1063, 980	Stone-faced soil bund (South Gonder, Hararghie, stabilized with grass, Tigray, stabilized stone-faced soil bund)		✓
1467	Traditional cut-off drains		✓
954	Grazing land improvement		✓
1418, 1414, 1048, 1598, 1072	Area closure (rehabilitation of degraded hillsides, for rehabilitation, on degraded lands, rehabilitation of degraded lands)		✓
1547, 1058, 1065, 1526,	Check dam (ponds, Dawa-Cheda traditional check dam, DireDawa traditional ceck dam, stone wall)		✓
1071, 1060, 1045, 1078, 1073, 1601, 1415	Soil bund (Boreda, Desho grass, graded, Haraghie, combined with fanya juu and vegetated, combined with contour cultivation, vegetated and graded)		✓
993	Homestead development		✓
1524	*Jatropha curcas* hedge		✓
1049	Improved grazing land management		✓
1061	Level bund with double stone walls		✓
978	Multiple cropping		✓
1079	Paved and grassed waterways		✓

PRACTICE CODES AS THEY APPEAR IN THE WOCAT DATABASE (www.wocat.net)	SLM TECHNOLOGY	COUNTRY WHERE PRACTICED	
		KENYA	ETHIOPIA
979	Ridge & basin		✓
1046	Ridge bund		✓
943	Runoff/floodwater farming		✓
1197, 991	Trench bunds (soil-faced deep trench bunds, stone-faced)		✓
1068	Sweet potato ridge		✓
1192	Teff row planting		✓
1074, 1067, 1336, 1243, 949, 1388	Terraces (hillside, Konso bench terrace, sorghum terrace of Diredawa (STD), vegetated fanya juu, terraces with Napier grass + sweet potatoes)	✓	✓
1738, 1146, 1212, 1159, 1339,	Agroforestry (coffee agroforestry, boundary trees-windbreaker, *Grevillea* agroforestry system, agroforestry land use in bench terraces with cut-off, agroforestry system (intercropping beans/ maize) with contour ditches, strips)	✓	
1597, 1469, 1490	Gully (erosion management, rehabilitation, gully blocking by stone checks)	✓	✓

Table A3 Summary information for the household groups (HGs) and their main practices

VARIABLES	DESCRIPTION OF THE MAIN HGs			
	Improve crop production and forage	Improve water harvesting/ reduction of flood and improved water drainage	Reduce soil erosion and land degradation (including through improved water infiltration)	1
	Kenya			**Total**
Households	8	6	31	45
Some selected practices (codes)	1212, 1325, 1580, 1569, 1146, 1567, 941, 1743	1484, 1485, 1486, 1489, 1537, 1483	1740, 1096, 1318, 1736, 1487, 1244, 1094, 1323, 1581, 1326, 507, 1735, 1570, 958, 1243, 1336, 1320, 1490, 1322, 940, 1095, 1097, 1135, 1676	
	Ethiopia			
Households	5	24	21	50
Some selected practices	954, 1072, 1063	1073, 1197, 1065, 1077, 980, 1060, 1069, 1074, 991, 1546, 978, 993, 1468	1418, 1598, 1067, 1597, 1058, 979, 1048, 943, 1066, 1068, 1061, 1049, 1524, 1078, 1389, 1601, 949, 1469, 1059, 1046, 1547, 1526, 1467, 1045	

Table A4 Description of the main variables that were used in clustering the households

VARIABLE NAME	VARIABLE DESCRIPTION
Country where applied	Country in which the technology was being studied and implemented
Primary goal	Final target output resulting from employing this technology
Sequester carbon	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on various strategies (1 if it enhances or sequesters, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (reduces erosion)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to reduce soil erosion (1 if it does, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (restores degraded land)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to restore degraded land (1 if it does, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (increases land biomass)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to increase land biomass (1 if it does, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (increases production)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to increase production of food or forage (1 if it does, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (improves biodiversity)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to improve biodiversity (1 if it does, 0 if it doesn't)
Possible strategy for analyzing how the technology influences soil carbon sequestration (improves groundwater)	A variable for the effectiveness of the technology in enhancing soil organic carbon sequestration based on the ability to improve groundwater (1 if it does, 0 if it doesn't)
Main purpose 1	The reasons for which this technology is being employed
Main purpose 2	The reasons for which this technology is being employed
Main purpose includes and encourages climate change adaptation	A variable indicating whether the reason for which this technology is applied leads to climate change adaptation (1 for it does, 0 for it doesn't)
Land use where applied	A variable indicating the type of land use on the farm where the technology was implemented
Other land use	A variable indicating other land-use types on the farm where the technology was applied
SLM group to which the technology belongs	Sustainable land management group into which this technology is classified or belongs
Land degradation addressed to prevent soil erosion	A variable confirming the type of land degradation addressed to prevent soil erosion (1 if it does, 0 if it doesn't)
Land degradation addressed to prevent biological degradation	A variable confirming the type of land degradation addressed to prevent biological degradation (1 if it does, 0 if it doesn't)
Land degradation addressed to prevent water degradation	A variable confirming the type of land degradation addressed to prevent water degradation (1 if it does, 0 if it doesn't)

Table A5 Carbon sequestering potential of SLM practices

SLM PRACTICE	C-SEQUESTRATING POTENTIAL	C- STOCK/ LOAD	C-ACCUMULATION	UNIT OF MEASUREMENT	PERIOD (YR)	COUNTRY		REFERENCES
						ETHIOPIA	KENYA	
Intercropping [d]	4.0 ± 2.2			t C ha^{-1} yr^{-1}		✓		Kim et al. (2016)
Silvopasture	14.0± 4.1			t C ha^{-1} yr^{-1}		✓		Kim et al. (2016)
Silvopasture	23.0	39.1	23.0	Mg C ha^{-1}	50	✓		Gelaw et al. (2014)
Improved fallow [d]	6.4 ± 1.0			t C ha^{-1} yr^{-1}		✓		Kim et al. (2016)
Rotational woodlands	14.0± 2.3			t C ha^{-1} yr^{-1}		✓		Kim et al. (2016)
Tree plantations [d]	6.8 ±0.7			t C ha^{-1} yr^{-1}		✓		Kim et al. (2016)
Enclosure [d]	300.4			t C ha^{-1}	20	✓		Bikila et al. (2016)
Enclosure		39.6 ± 3.5		Mg ha^{-1}	<20	✓		Feyisa et al. (2017)
Enclosure		40.8 ± 3.4		Mg ha^{-1}	20–30	✓		Feyisa et al. (2017)
Enclosure		51.0 ± 4.4		Mg ha^{-1}	>30	✓		Feyisa et al. (2017)
Natural forests		49.7-129.3		Mg ha^{-1}		✓		Tesfaye et al. (2016)
Croplands [d]		14.3-43.6		Mg ha^{-1}		✓		Tesfaye et al. (2016)
Plantations								
Eucaliptus saligna		33.5-90.8		Mg ha^{-1}		✓		Tesfaye et al. (2016)
Cupressus lusitanica		26.8-66.7		Mg ha^{-1}		✓		Tesfaye et al. (2016)
Pinus patula		25.0-63.0		Mg ha^{-1}		✓		Tesfaye et al. (2016)
Biogas technology [d]	243.3			CO_2e yr^{-1}		✓		Mengistu D et al. (2016)
Conserved watershed [d]		61·54		Mg ha^{-1}		✓		Mengistu MG et al. (2016)
Indigenous agroforestry								
Tree-coffee		301		Mg C ha^{-1}	10–40	✓		Negash and Kanninen (2015)
Enset-coffee-tree		286		Mg C ha^{-1}	10–40	✓		Negash and Kanninen (2015)
Enset-tree		209		Mg C ha^{-1}	10–40	✓		Negash and Kanninen (2015)

SLM PRACTICE	C-SEQUESTRATING POTENTIAL	C- STOCK/ LOAD	C-ACCUMULATION	UNIT OF MEASUREMENT	PERIOD (YR)	COUNTRY		REFERENCES
						ETHIOPIA	KENYA	
Agroforestry [d]		20.0-25.4		C, kg per Mg	6–20	✓		Rimhanen et al. (2016)
Agroforestry		25.8	9.7	Mg C ha^{-1}	50	✓		Gelaw et al. (2014)
Restrained grazing		11.0-18.0		C, kg per Mg	6–17	✓		Rimhanen et al. (2016)
Terracing [d]		6.0-8.0		C, kg per Mg		✓		Rimhanen et al. (2016)
Communal pasture [d]		52.6	36.5	Mg C ha^{-1}	50	✓		Gelaw et al. (2014)
Irrigation [d]		24.4	8.3	Mg C ha^{-1}	50	✓		Gelaw et al. (2014)
Croplands			2.9-14.6	Tg C	25		✓	Batjes (2004)
Forestry		109.8		Mg C ha^{-1}			✓	Were et al. (2017)
Forestry		95.1-118.7		g kg^{-1}			✓	Solomon et al. (2007)
Grasslands [d]		103.4		Mg C ha^{-1}			✓	Were et al. (2017)
Croplands		95.8		Mg C ha^{-1}			✓	Were et al. (2017)
Tillage		0.25-0.32		C kg m^{-2}	9		✓	Margenot et al. (2017)
Residue management		0.4		C kg m^{-2}	9		✓	Margenot et al. (2017)
Inland riverine and palustrine wetland		80.0-100.0		t C ha^{-1}			✓	Minasny et al. (2017)
Mangrove		3.6-29.7		kg m^{-2}			✓	Andreetta et al. (2014)
Conventional tillage		25.0-195.2		kg ha^{-1}	8		✓	Okeyo et al. (2016)
Mulching [d]		11.6-90.5		kg ha^{-1}	8		✓	Okeyo et al. (2016)
Minimum tillage [d]		106.1-111.8		kg ha^{-1}	8		✓	Okeyo et al. (2016)
Tied ridge [d]		12.5		kg ha^{-1}	8		✓	Okeyo et al. (2016)

SLM PRACTICE	C-SEQUESTRATING POTENTIAL	C- STOCK/ LOAD	C-ACCUMULATION	UNIT OF MEASUREMENT	PERIOD (YR)	COUNTRY	REFERENCES
Change in land management						**EAST AFRICA** (Ethiopia, Kenya, Rwanda, Tanzania, Uganda, and Rwanda)	
Cropland to cropland + farmyard manure		7.6 ± 7.3		t C ha^{-1} yr^{-1}	<10		Namirembe et al. (unpublished)
Cropland to cropland + crop residue		13.2 ± 2.6		t C ha^{-1} yr^{-1}	<10		"
Cropland to agroforestry		1.34		t C ha^{-1} yr^{-1}	<10		"
Cropland to cropland + fallow		0.8		t C ha^{-1} yr^{-1}	<10		"
Cropland to cropland + improved fallow		1.6 ± 1.8		t C ha^{-1} yr-^{1}	<10		"
Cropland to cropland + legume		17.0		t C ha^{-1} yr^{-1}	<10		"
Cropland to cropland + fertilizer		2.3 ± 3.0		t C ha^{-1} yr-^{1}	<10		"
Cropland + terracing		0.24		t C ha^{-1} yr^{-1}	<10		"
Cropland to cropland + FYM + fertilizer		7.3 ± 6.8		t C ha^{-1} yr^{-1}	<10		"
Cropland to forest plantation[d]		1.27		t C ha^{-1} yr^{-1}	<10		"

NB: [d] represents practices that were reviewed.

Appendix 1. General biophysical and socioeconomic characteristics of the study sites

Kenya

Most of the reviewed studies in Kenya were conducted in areas where SLM practices can potentially improve crop and livestock yields. A majority of these studies were conducted in Western Kenya because of its good potential for agriculture, relatively high rainfall, and well-drained soils that support the growth of food crops. However, the fertility of the soils is inherently low due to continuous cropping over the years. Western Kenya covers a land area of 7,400 km^2 and falls between the humid and sub-humid agro-ecological zones, with a bimodal distribution of rainfall ranging from about 1,200 mm to 2,000 mm annually. The altitude and the annual temperature range from 1,300 to 1,500 meters above sea level (masl) and 15 to 29 °C, respectively. The Eastern region occupies 140,699 km^2 and falls mostly in the semi-arid agro-ecological zone, where rainfall is unreliable and recurrent droughts are common. The area is characterized by shallow soils with low organic matter content and declining soil fertility. The altitude is 1,560 masl, with annual rainfall ranging from 350 to 800 mm. The study areas in the Rift Valley region span arid, semi-arid, and semi-humid agro-ecological zones, with low, unreliable, and poorly distributed rainfall. The soils are poorly drained and saline, with annual rainfall ranging from 400 to 1,200 mm. The area covers 182,505 km^2 at an altitude ranging from 900 to 1,900 masl. The Central region covers a land area of 13,191 km^2 with fairly reliable rainfall, characterized by vertisols that have varied organic matter content. The area traverses sub-humid and semi-arid agro-ecological zones with changing altitudes, which can be as low as 1,500 m and as high as 4,000 m, affecting rainfall and temperature distribution. Rainfall in the lowest areas can be 450 mm, with 2,000 mm in the highest areas; temperatures range from 16 to 19 °C, where night temperatures can go as low as 10 °C.

Ethiopia

In Ethiopia, climatic conditions vary with altitude and temperature. The areas in the plateau zone (e.g., Harar) vary in altitude, from 1,700 to 2,300 masl; annual rainfall ranges from 850 to 1,200 mm. The arid and semi-arid zones (e.g., Tigray and Somali) that surround the plateau are lower altitude areas with declining rainfall. Annual rainfall can be as low as 700 mm, while temperatures can be as high as 28 °C, with extremes of 40 °C in some months. Altitude varies, with lower regions at 1,000 m and higher regions at 2,000 m. In the Danakil zone (e.g., Afar), the climate is desert and hot throughout the year. The altitude is as low as 125 m below sea level and the area is regarded as one of the hottest regions in the world, with temperatures ranging from 30 to 35 °C throughout the year. Traditionally, Ethiopia is divided into five climatic zones (Table A6), under which the above areas fall.

Table A6 Biophysical characteristics in **Ethiopia**

CLIMATIC ZONE	ALTITUDE (M)	MEAN RAINFALL (MM)	MEAN TEMPERATURES (°C)
Hot-arid *(Bereha)*	<500	395	26–35
Semi-arid *(Kolla)*	500–1,500	550–1,600	22–29
Semi-humid *(Woina Dega)*	1,500–2,500	1,250–2,450	18–21
Humid *(Dega)*	2,500–3,200	1,100–2,100	11–17
Moist-mild *(Wurch)*	3,200–3,500	<900	<9

Appendix 2. Descriptive results on sustainable land management technologies from the WOCAT database for Kenya

The results in Table A7 show that the majority of households practicing SLM in Kenya does it extensively – implying the use of low inputs, low capital, and less labor. The results showed that 67% of these households own 2 ha of land or less. This finding echoes Pisanelli et al. (2008), who observed that households that were adopters of SLM technologies in Kenya own land whose size ranges from 1 to 2 ha. Chikowo et al. (2014) also observed that the average size of land for farmers that practice SLM in the Kenyan highlands ranges from 0.2 to 2 ha. According to García de Jalón et al. (2015), households with large farm size have more resources that enable them to accomplish agricultural tasks better than those with smaller farms.

About 51% of the studied households have a mixed market orientation, with only very few aligned to commercial farming. About 60% of the households are in the middle-income category, with approximately 50%, 20%, and 17% having an annual off-farm income of USD 100 or less, from USD 100 to USD 500, and above USD 500, respectively. This finding resembles those of Simtowe and Muange (2013), who found that the average income per annum for households in communities where the adoption of SLM is widespread is about USD 130.

The decisions relating to SLM practices are made jointly by the male and female in slightly more than 50% of the studied households. Access to technical assistance for SLM practices is moderate. However, for adopters of SLM that enhances soil carbon sequestration, access to technical information was significantly higher than for non-adopters. In more than 70% of the households, the benefits vs costs can be evaluated as positive in the short run, which means that they are proficient in cutting cost or use with low-cost technologies. Mugwe et al. (2009) observed that the adoption of techniques such as manure and fertilizer application is typical in Kenya because these techniques tend to be the most financially and socially profitable. On a scale of 1-10, the practices are rated at 7, with the benefits in the short run outweighing the costs (or exhibiting positivity). The main costs incurred when implementing SLM practices in the short run are labor costs, followed by the cost for maintaining inputs (Table A8).

Table A7 Summary information on some selected socioeconomic variables among households in **Kenya**

VARIABLE		FREQUENCY	PERCENTAGE
Production system	Extensive land use	39	86.7
	Intensive land use	5	11.1
	Both extensive and intensive	1	2.2
Gender	Joint decision	23	51.1
	Female	5	11.1
	Male	2	4.4
Wealth status	Middle income	27	60.0
	Poor	9	20.0
	Rich	7	15.6
Market orientation	Mixed	26	57.8
	Commercial	3	6.7
	Subsistence	2	4.4

VARIABLE		FREQUENCY	PERCENTAGE
Off-farm income	<USD 100	24	53.3
	USD 100-500	9	20.0
	>USD 500	8	17.8
Land size	0.5-2.0 ha	20	44.4
	<0.5 ha	8	17.8
Technical assistance	Moderate	9	20.0
	Poor	3	6.7
	Good	3	6.7
Benefits-establishment costs (short run)	Positive	22	48.9
	Slightly positive	10	22.2
	Negative	8	17.8
	Very positive	1	2.2
	Neutral	1	2.2
Benefits-maintenance costs (short run)	Positive	29	64.4
	Slightly positive	7	15.6
	Very positive	4	8.9
	Very negative	4	8.9
	Neutral	2	2.2

N=45. The percentages need not add up to 100% because of missing responses.
Source: WOCAT database (www.wocat.org). USD stands for United States Dollar.

Table A8 The mean and standard deviation of the main costs incurred in the adoption of SLM practices in **Kenya**

VARIABLE	MEAN	STD. DEV.
Establishment cost of labor	315.7	950.9
Maintenance cost of labor	229.5	1,118.2
Maintenance cost of inputs	189.8	1,101.5
Strength	7.7	3.3

Note: The costs are in U.S. dollars (USD 1 = KSH 102). Sample size (n) = 45.

Appendix 3. Descriptive results on sustainable land management technologies from the WOCAT database for Ethiopia

The results in Table A9 show that decisions relating to the adopted technologies are mostly made by men. Close to 70% of the households have an off-farm income of less than USD 100 per annum, with 34% and 50% of the households being rated as middle income and poor, respectively. Agricultural production is mainly for subsistence, with only a few farmers practicing it for commercial purposes (Table A9). More than half of the farming households in Ethiopia live below the national poverty line, with an over-reliance on agricultural income (Deininger and Jin, 2006). Of all the studied households that have adopted various SLM technologies, about 20% and 60% reported a poor and moderate knowledge (i.e., on how to implement the technologies), respectively. Although adoption of the technologies is spontaneous and without incentives, it varies among households so that only about 30% of the studied households reported having adopted various practices; the main constraint being the lack of availability of cheap labor.

In most of the areas where SLM is practiced, planting is the most important establishment activity for about 80% of the households. According to Benin and Pender (2001), areas with a high population density tend to have smaller farms and tend to intensify their farming in order to maximize on production. Moreover, the cost of establishing inputs is almost three times higher when compared with the maintenance costs (Table A10). However, the costs of tools and equipment are cheaper. It is observed that benefits in both the short and long run are positive, which could be an incentive for the adoption of SLM technologies. However, the benefits are higher in the long run than in the short run.

Table A9 Summary data for some selected socioeconomic variables among households in **Ethiopia**

VARIABLE		FREQUENCY	PERCENT
Gender	Male decision	11	22
Knowledge of technology use	Low	10	20
	High	11	22
	Moderate	28	56
Wealth status	Middle income	26	52
	Poor	17	34
Population density	50–100 people/km^2	9	18
	100–200 people/km^2	21	42
	200–500 people/km^2	14	28
Market orientation	Mixed	18	36
	Subsistence	23	46
Off-farm income	<USD 100	34	68
	USD 100–500	10	20
% of spontaneous adopters without incentive	Very weak	15	30
	Weak	5	10

VARIABLE		FREQUENCY	PERCENT
% of spontaneous adopters without incentive	Moderate	5	10
	Very strong	18	36
Adoption due to cheap labor	No	35	70
	Yes	15	30
Non-adoption due to reduced cultivation land	No	42	84
	Yes	8	16
Planting as an establishment activity	No	10	20
	Yes	40	80
Pruning as a maintenance activity	No	42	84
	Yes	8	16
Maintenance costs	Labor	45	90
	Inputs	5	10
Benefits-establishment costs (short run)	Slightly positive	17	34
	Positive	18	36
	Negative	12	24
Benefits-establishment costs (long run)	Positive	28	56
	Very positive	18	36

NB: The percentages do not add up to 100% due to some missing responses. Sample = 50. USD stands for United States Dollar.

Table A10 Summary information on costs incurred in the adoption of practices that enhance soil carbon sequestration in **Ethiopia**

VARIABLE	MEAN	STD. DEV.
Establishment cost of inputs	592.9	2,315.3
Establishment cost of tools & equipment	86.8	179.7
Maintenance cost of inputs	135.8	662.9
Rate of stabilization of dry-season stream flows	4.6	4.4
Rate of reduction in groundwater/river pollution	1.5	3.3

NB: The percentages do not add up to 100% due to some missing responses. Sample = 50. USD stands for United States Dollar.

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